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BEARING METAL ALLOYS.*

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It is undoubtedly well known that what in technical language is called a "bearing," is a piece of metal (usually an alloy) which lies next to a revolving shaft or axle, or other revolving part of machinery, and sustains the load. The shape of the bearing may be such as to completely inclose the revolving shaft, or to cover only perhaps one-third of it. In car boxes the latter is true; the bearing rests on that portion of the axle, which is technically known as the journal, and on top of the bearing rests the weight of the car. In other situations, as for example in the case of crank-pins, and in many cases with shafting, the bearing metal encircles the revolving part, and has only as

* Abstract of a lecture delivered before the Franklin Institute.

much play or space between it and the revolving part as is essential for smooth running. It is also doubtless well known that the space between the bearing and the revolving part, be it a portion of the axle, or of the crank-pin, or of a shaft, is commonly lubricated. It may also be fair to add, that what is commonly known as a "hot box" in railroad language, is in reality a hot bearing and the portion of the axle underneath it.

The amount of metal used to make bearings is something enormous. To my knowledge, one large corporation uses not less than 1,000,000 to 1,250,000 pounds per year of bearing metal, and it can readily be seen why this should be so, from knowing that each bearing weighs from ten to fifteen pounds, and that each car has not less than eight, while some cars have twelve. Also, it is not at all uncommon for large railroads to build 5,000 cars at a time, which, as is readily seen, means 500,000 pounds of bearing metal. Still farther, it is a fairly good bearing metal that will not lose as much as a pound of its weight in a single bearing for every 25,000 miles that it goes under a car; so that the amount of new metal required to make up the loss by wear is something enormous, when the total car mileage, both freight and passenger, of the United States is taken into account. I have never seen any positive statement as to the amount of bearing metal used in a year in the United States, but the above considerations, in addition to the fact that bearing metal costs all the way from twelve to twenty cents per pound, will show that the money involved in bearing metals per year is a very large figure.

It has already been hinted that bearing metals are usually made out of alloys, and the question naturally arises why alloys are used. Why not use cast iron, or, indeed, some of the same metal of which the journal itself is to consist? I have never heard any entirely satisfactory reason, but it is commonly stated that a bearing and a journal of the same metal do not work well together. The wear is claimed to be more rapid, and the friction greater, when both the bearing and the journal are of the same

metal. This would clearly explain why it would not be advisable to use wrought-iron or steel bearings. The same reasoning would not quite apply to cast iron, and, indeed, it is well known that in certain places in mechanics cast iron is used on cast iron, and also cast iron is used as a bearing metal where the journals are either wrought iron or steel. It seems fairly probable, however, that there is another reason beside the one already hinted at, connected with the wear and friction, why alloys are so largely used for bearings, namely, that alloys generally have a very much lower melting point than either cast iron or steel, and are therefore much more easily manipulated and gotten into the shape required. Moreover, there is still another reason that has been urged with a good deal of force, namely, that the journal is usually much more valuable than the bearing; that is to say, when the journal has worn a certain amount, the whole axle, crank-pin, or shafting perchance, must be replaced, so that the actual value of the axle, crank-pin or shafting is represented by a a thin layer of metal at the journal. If, now, a metal is used as bearing metal that increases the wear of the journal, the total loss will be much greater than if a metal is used, which itself wears away rapidly, but allows the journal to wear more slowly. This is believed to be the case with alloys. The bearings themselves are easily replaced, the journals are more difficult to replace, and are much more expensive, taken as a whole, and consequently it is good policy to use for a bearing metal something which will take the wear, rather than have it appear in the journals.

It may not be amiss to state what may be regarded as a good bearing metal. There may be five characteristics of a good bearing metal.

(1) The bearing must hold up the load. It is doubtless well known that in railroad practice, the pressure per square inch on the bearing metal is frequently as high as 350 to 400 pounds per square inch, and consequently it is absolutely essential that the bearing metal should be of such a nature that it will sustain this pressure without distortion. Moreover, it is doubtless well known that in ordinary railroad

practice, when the journal of the axle becomes somewhat worn, and it becomes necessary to put on a new bearing, there is not a perfect fit between the bearing and the journal since the bearings are all bored to the same radius, it being impossible to bore them for all possible conditions of worn journals. It follows that the bearing only touches the journal theoretically along a line, but actually the amount of surface involved is considerably more, and as most bearings in modern practice are lined with a coating of lead about one-eighth inch thick, it is only a short time before a good contact, embracing pretty nearly all the surface, is formed. But it is clear that the strain introduced in the bearing when it is put on a journal somewhat smaller than the radius to which the bearing is bored has a tendency to break the bearing in two lengthways, and the metal must therefore be of sufficient strength to resist this strain. Metallic lead, and indeed many of the white metal alloys, consisting of lead and antimony, lead, tin and copper, etc., are rarely used, so far as our knowledge goes, in car-journal bearings on this account, namely, although they may be good for certain reasons, they are hardly sufficiently strong, nor will they sufficiently well hold up the load to enable successful bearings to be made of them. They are frequently used, however, as linings, from one-eighth to possibly one-quarter or three-eighths inch thick, in a shell of stronger metal. Such composite bearings are very good, but their superiority over a bearing of the proper kind of metal does not seem to be sufficient, so far as my knowledge goes, to warrant the trouble of making the composite bearings.

(2) Another requisite of a good bearing metal is that it does not heat readily. Upon this point there is not as much information as could be desired. I have known of experiments with trial bearings in which three out of four heated within the first day or two, but it is always an open question as to whether this is due to the metal or some other concomitants of the service. It is also known by actual test on a large number of bearings that the old copper-tin bearing metal of seven parts copper to one of tin, results in a very much larger percentage of hot boxes than some of the alloys,

which will be mentioned later on. The general tendency of all the information which is at hand on this subject, is that the harder the bearing metal is, the more readily it will heat, or to put it in another form, the softer the alloy the less liability there is for the bearing to get hot in service.

(3) Another important requisite of a good bearing metal is that it shall work well in the foundry. It may, perhaps, make this point clear if I explain that bearing metal is usually melted in crucibles, holding from 100 to 500 pounds each, the crucible being placed in a hole made for the purpose above a grate, and surrounded with burning coal or coke. It is customary to cover the pot with the bottom of an old crucible, and to spread over the top of the molten metal, pounded charcoal. Yet despite these precautions, it is very common for the metal in the crucible, during the process of melting, and after it has become melted, to take up large quantities of oxygen from the air, forming oxides of the metal. When this takes place the castings made from such metal are always more or less spongy and inferior. It should be stated that with careful foundry practice, namely, with sufficient care in the melting to keep the metal well under pulverized charcoal, and also after the pot is taken from the fire to stir it thoroughly with pulverized charcoal, adding perhaps a little bit of metallic zinc, this difficulty can be largely overcome, but with a foundry where a large output is expected every day, the necessary care and time to secure solid castings with certain alloys, very seriously interferes with the work, and in many cases cannot be given, so that from the foundry standpoint, it is highly important, that the bearing metal used should be such a one as will give solid castings with the least possible effort and care in the foundry. So far as my knowledge goes, two things as constituents in bearing metal lead to this result: (1) from one to two per cent. of zinc in almost all the alloys used as bearing metal, makes it much easier to get sound castings, than if the zinc is not present; (2) the addition of a small amount of phosphorus either in the form of phosphor-tin, or in fact in the form of any of the phosphorized alloys to be obtained in the market, is always valu-

able for this purpose. The latter, namely, the phosphorus, is to our minds one of the principal elements of value in the well-known alloy "phosphor-bronze bearing metal." It is probably beyond question that with ordinary foundry practice a very much larger percentage of sound castings will be obtained from using the phosphor-bronze bearing metal, than from using the same constituents without the phosphorus.

(4) A good bearing metal should show small friction. Upon this point it may be urged that the friction is almost wholly a question of the lubricant used, and all the experiments that I have seen confirms this view to a greater or less extent, namely, that the largest portion of the friction between a bearing and a journal, is a function of the lubricant used. On the other hand, the nature of the bearing metal does certainly have an influence, and a good bearing metal is one which makes that element of the friction depending on the bearing metal as small as possible. I do not know of much experimentation on this subject. Such experiments are extremely difficult to make on account of the large number of variables, notably temperature, quantity of oil between the surfaces, pressure, speed, relative smoothness of the journal and bearing, etc. It is very greatly to be desired that careful experimentation in this field should be made.

(5) It is extremely important that a bearing should give high mileage with small loss of metal by wear. It has already been stated that the average bearing metal used under cars loses one pound for every 25,000 miles that the bearing goes. Many bearing metals wear much faster than this, and some slower, but other things being equal, no one will dispute that that bearing metal is best which wears the slowest. Some data on this point will be given a little further on.

The common metals from which alloys are made for bearings may, perhaps, be enumerated as follows: Copper, tin, lead, zinc, antimony, iron and aluminium. It is, of course, possible for manganese, silicon, bismuth, mercury, cadmium, nickel, cobalt, sulphur, arsenic and phosphorus

to occur either as essential or accidental constituents of bearing metal alloys. The last two are not rare, and are purposely used. The combinations of these are quite numerous, and it will be observed that the possibilities of combination are very great. There is not only the different kinds of metal, but the different proportions. During my experience, now of some fifteen years, there have been analyzed in the laboratory of the Pennsylvania Railroad Company, a good many bearing metals under various names, and for the sake of record some of these analyses are given, as follows:

CAMELIA METAL.

	Per Cent.
Copper,	70·20
Tin,	4·25
Lead,	14·75
Zinc,	10·20
Iron,	0·55

ANTI-FRICTION METAL.

Tin,	98·13
Copper,	1·60
Iron,	trace

WHITE METAL.

Lead,	87·92
Antimony, by difference,	12·08

METAL FOR LINING CAR BRASSES.

Lead,	84·87
Antimony,	15·10
Tin,	trace

SALGEE ANTI-FRICTION METAL.

Zinc,	85·57
Tin,	9·91
Copper,	4·01
Lead,	1·15

GRAPHITE BEARING METAL.

Lead,	67·73
Tin,	14·38
Antimony,	16·73
Iron,	not determined
Graphite,	none

ANTIMONIAL LEAD.

	Per Cent.
Lead,	80·69
Antimony, by difference,	18·83

CARBON BRONZE.

Copper,	75·47
Tin,	9·72
Lead,	14·57
Carbon,	possible trace

CORNISH BRONZE.

Copper,	77·83
Tin,	9·60
Lead,	12·40
Zinc,	trace
Iron,	trace
Phosphorus,	trace

DELTA METAL.

Copper,	92·39
Tin,	2·37
Lead,	5·10
Iron,	0·07

MAGNOLIA METAL.

Lead,	83·55
Antimony, by difference,	16·45

Traces of iron, copper zinc, and possibly bismuth.

AMERICAN ANTI-FRICTION METAL.

Lead,	78·44
Antimony,	19·60
Zinc,	0·98
Iron,	0·65

TOBIN BRONZE.

Copper,	59·00
Zinc,	38·40
Tin,	2·16
Iron,	0·11
Lead,	0·31

GRANEY BRONZE.

Copper,	75·80
Lead,	15·06
Tin,	9·20

DAMASCUS BRONZE.

Copper,	76·41
Tin,	10·60
Lead,	12·52

MANGANESE BRONZE.

	Per Cent.
Copper,	90·52
Tin,	9·58
Manganese,	none

AJAX METAL.

Copper,	81·24
Tin,	10·98
Lead,	7·27
Phosphorus or arsenic,	0·37

ANTI-FRICTION METAL.

Lead,	88·32
Antimony,	11·93

HARRINGTON BRONZE.

Copper,	55·73
Zinc,	42·67
Tin,	0·97
Iron,	0·68

CAR BOX METAL.

Lead,	84·33
Antimony,	14·38
Iron,	0·61
Zinc,	trace

HARD LEAD.

Lead,	94·40
Antimony,	6·03

PHOSPHOR-BRONZE.

Copper,	79·17
Tin,	10·22
Lead,	9·61
Phosphorus,	0·94

EX. B METAL.

Copper,	76·80
Tin,	8·00
Lead,	15·00
Phosphorus,	0·20

It will be understood that the above analyses represent many metals offered by many different parties, sometimes under the same name. These analyses are selected from the many that have been made in the laboratory of the Pennsylvania Railroad, during the last twelve or fifteen

years, and are simply put on record for whatever value they may have. It will be observed that copper, tin, lead, antimony and zinc, are the common metals used, and that iron is not a rare constituent. In some cases where there were very small amounts of other metals, they have not been determined, and sometimes may fairly be regarded as impurities. At other times perhaps they are essential constituents. I know of one or two cases where this latter is claimed, but our experiments have not gone far enough to prove whether these small amounts of other constituents are of value or not. On the other hand, it is well known that a small amount of iron imparts to a copper-zinc alloy quite wonderful properties. In the case of the so-called Harrington bronze, the analysis of which is given above, the alloy after it had been rolled, actually had a tensile strength of 75,000 pounds per square inch, and an elongation of about 20·00 per cent. in a two-inch section. Quite a large number of other alloys have either been examined qualitatively, or put on trial during the last fifteen years. Aluminium-bronze has not yet been tried, but it is now under consideration.

In view of the quite large number of metals which may be used to make alloys, and in view of the different properties which result from different proportions of these metals in the same alloy, it is perhaps not strange that the whole question of bearing metals, should be regarded as more or less uncertain. What ones of these five or six different metals shall be combined to make a successful bearing metal, and shall we use them all in the same alloy, or shall we use part, and more important than all, perhaps, after we have decided what metals shall be used in the alloy, what proportion of each shall be used. It is perhaps not too much to say that this difficult problem cannot be regarded as completely worked out as yet. A good deal has been done but much remains to be done, and it is entirely possible that future knowledge, as the result of careful experiment, will change many of the views that are now held in regard to the composition of bearing metal alloys.

It is undoubtedly entirely natural that in attempting to

find out what the best bearing metal is, the ones in use should be taken as the starting point. This was the case with the experiments that have been conducted on the Pennsylvania Railroad. Most people are aware that fifteen or twenty years ago, the standard metal used in car bearings, and other places was a simple copper-tin alloy, containing seven parts of copper to one of tin. Indeed, some railroads, if I am rightly informed, and some builders of machinery, even at the present time use cannon bronze, or the seven to one copper and tin alloy as bearing metal. It will be seen as I proceed that we regard this as a serious mistake; that while perhaps we do not know what the best bearing metal is, we do know something very much better than the copper-tin alloy.

It will, perhaps, be essential to describe the method of experimentation, before proceeding, to show what modifications in the copper-tin alloy have been made use of in trying to throw some light on the question of the best bearing metal alloy.

The method in all cases has been to have a certain number of bearings made of a standard bearing metal, which will be described later on, and the same number of bearings of the experimental metal. These bearings were placed on opposite ends of the same axles, either on locomotive tenders or on cars, one-half of the standard and experimental bearings being on one side of the car, and the other half being on the other side, but in all cases a standard bearing and an experimental bearing on opposite ends of the same axle. The bearings were all carefully weighed before going into service, and after a sufficient lapse of time were taken out and re-weighed. At first an attempt was made to give the loss of metal by referring it to the mileage, but the method of comparison was ultimately adopted, as giving results free from any possible difficulties introduced by mileage, so that all the results which we obtained are strictly comparative.

The standard bearing metal is what is known in the market as phosphor-bronze bearing metal, technically described by the Phosphor-Bronze Smelting Company as the "S Bear-

ing Metal." This metal contains, approximately, 79·70 per cent. of copper, ten per cent. of tin, 9·50 per cent. of lead, and about 0·80 per cent. of phosphorus. It is, of course, a fair question, and one which has not been overlooked, whether the standard bearing metal gives uniform wear. A large number of experiments have been made on this point, the result being that the average wear of standard phosphor-bronze, compared with the mileage, is best expressed by saying that the phosphor-bronze bearing metal loses one pound of metal, worn off, for every 18,000 to 25,000 miles of travel. This, it will be observed, shows a discrepancy in the wear of the standard phosphor-bronze bearing metal, and this fact led us to abandon the method of making comparisons by mileage. The reasons for the discrepancy are not hard to find: (1) The pressure per square inch in all tests was not the same, and consequently the wear would not be the same. On the other hand, with bearings on the opposite ends of the same axle, the pressures per square inch are approximately the same. (2) The state of the lubrication in different cars and engines, which is more or less characteristic of different parts of the road, is a very important variable, and undoubtedly goes far towards explaining the differences in mileage above given. This variation in the state of lubrication is not so apt to be characteristic of opposite ends of the same axle, as it is of different cars and locomotives. I am inclined to think, therefore, that the assumption that standard phosphor-bronze is sufficiently uniform in its behavior to warrant its being used as the basis of comparison will not lead us into serious error, at least if we confine ourselves to a direct comparison of the loss of metal obtained from standard bearings on one end of the axles and experimental bearings on the other end of the same axles. Usually sixteen bearings of each kind were put in service as a preliminary experiment, and if the metal proved at all favorable on this preliminary trial, a larger trial, embracing fifty or 100 bearings of each kind, was put in service. The preliminary trials were usually made on locomotive tenders, where the bearings get the best possible care. The larger trials were more commonly made on

cars. Of course, owing to the exigencies of the service, it sometimes happened that some of the bearings put in use were not returned to be weighed. This was more true where bearings became heated, and were removed at different points along the line, than at the regular inspection points. Whenever, from any cause, a bearing was missing, its opposite was not taken into account, so that in reality in the results given the comparisons are strictly between the same number of standard and experimental bearings on opposite ends of the same axles. Sometimes as high as one-half the bearings in an experimental lot would be lost. In other cases nine-tenths would be returned.

[*To be continued.*]

EXPERIMENTS MADE TO ASCERTAIN THE SPECIFIC VOLUMES OF THE SATURATED VAPORS OF WATER, BISULPHIDE OF CARBON, AND ETHER, TOGETHER WITH VARIOUS MEASURES CONCERNING THE LATTER; ALSO THE DETERMINATION FROM THE EXPERIMENTAL DATA THUS OBTAINED OF THE MECHANICAL EQUIVALENT OF HEAT.

By A. Perot.

Translated by Chief Engineer Isherwood, U. S. Navy.

[*A thesis presented to the Faculty of Sciences of Paris.*]

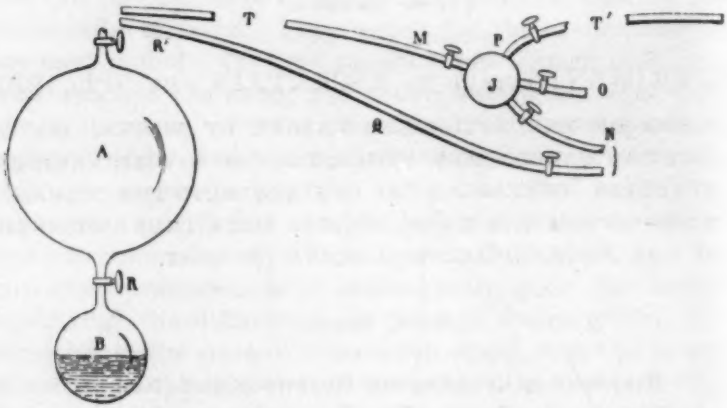
[*Concluded from p. 68.*]

Second Method.—I shall show the principle of this method by describing an imaginary experiment with it.

Suppose a receptacle A (*Fig. 5*), of known capacity put in communication by means of the cock R with a reservoir B containing some liquid, and by means of the cock R', either with a pneumatic machine or with the atmosphere. The apparatus having been raised to a certain temperature, and a vacuum made in A, if the cock R be opened, the cock R' remaining closed, A will be filled with saturated vapor, owing to the presence of the liquid continuing in B. If R be now

closed a known volume of saturated vapor will be isolated. Through the cock R', and by the aid of the pneumatic machine, draw out this vapor over absorbents placed between the cock and the machine. Knowing the volume of the receptacle A, and the increased weight of the absorbent tubes, which increase is the weight of the vapor that occupied the space A, there can be obtained by dividing the one into the other the specific volume of the saturated vapor. This method easily allows repetition of the trials, for there could be accumulated in the absorbent tubes the vapor corresponding to any number of trials, for which purpose there

FIG. 5.



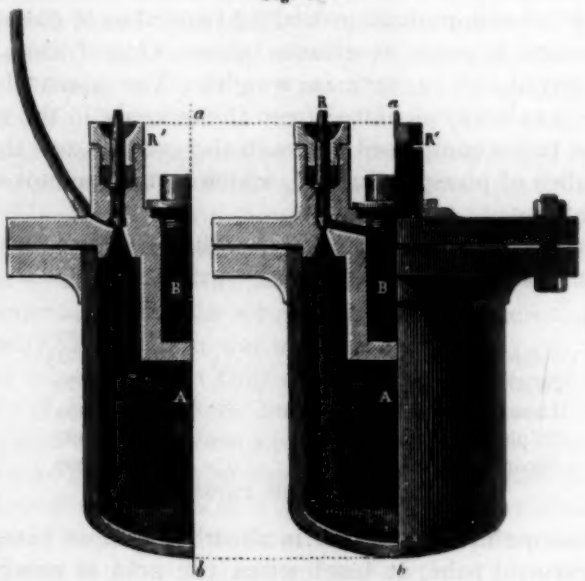
would only be required to make anew the vacuum in A, and recommence the operation in the same manner as before.

To realize the method just described, I employed the following apparatus (*Fig. 6*): A pot-shaped boiler of a little more than one litre capacity being closed by a bronze cover, constitutes the space A. The reservoir B forms part of the cover and projects downward into the boiler, its temperature being consequently exactly the same as that of the boiler; it is fastened by screws. The cocks R and R', which are the analogues of those having the same letters in the preceding figure, are packed cocks having their stuffing boxes filled with mixed cork and talc to avoid any trace of grease; for this purpose, too, all the joints are made with lead. The

boiler is plunged into a water-bath, where it is supported upon points and held fixed so as not to move when the cocks are turned. The entire interior is gilded so as to certainly avoid any attack of the metal by the vapor or the liquid, by presenting a continuous surface of a homogeneous metal but little liable to be affected.*

The following is the manner of making an experiment on ether (*Fig. 5*):

Fig. 6.



From a central point of junction *J* there goes a tube *M* containing the absorbents *T* and uniting with the cock *R'*. Also the tube *N* uniting with the mercurial pneumatic machine. Also the tube *O* uniting with the Carré machine. Finally, the tube *P* united by its end to a series of tubes *T'*, destined to arrest the atmospheric carbonic acid and aqueous vapor. These tubes contain two pots of caustic potash, two pots of sulphuric acid, four large tubes with sulphuric pumice, a column of anhydrous potassa of about thirty centimetres, and a column of the same length of phosphoric

* This apparatus was constructed with great perfection by Mr. Ducretet.

acid. A last tube Q allows the space A to be put in direct connection either with the mercurial machine or the Carré machine, without passing through the series of tubes T.

The absorbent tubes that I have employed for the vapor of ether are, commencing at the boiler, the following: from two to four Liebig tubes containing pure sulphuric acid for absorbing the vapor, a tube with lime mixed with some soda for absorbing the sulphurous acid which might be disengaged by the action of the sulphuric acid on the ether, a tube of sulphuric pumice preceding two tubes of phosphoric acid destined to serve as witness tubes. One of these tubes at least ought not to vary in weight. The mass of ether absorbed has been calculated from the increase in the weight of all the tubes comprised between the cock R' and the first of the tubes of phosphoric acid, which latter has not varied in weight.

As an example, the following are the results of an experiment comprising two tubes of sulphuric acid:

No. of Tube.	*Name of Absorbent.*	*Gain. grams.*	*Loss*
1,	Sulphuric acid,	2·56625	0
2,	Sulphuric acid,	0·0070	0
3,	Lime mixed with some soda,	0·0030	0
4,	Sulphuric pumice,	0·0000	0
5,	Phosphoric acid,	0·0000	0

Mass of ether absorbed, 2·5762 grams.

As shown above, the ether is absorbed almost integrally in the first acid tube, at least when the acid is newly prepared, as was the case in the experiment cited; the acid should be changed with each experiment because after being once used it disengages sulphurous acid, a perturbation that should be avoided.

I have said that with this apparatus a method of repetition could be employed, nevertheless, I have limited myself to one time only, because in a single simple experiment lasting about four hours, the disengagement of sulphurous acid which I have mentioned above commences at the close of the second experiment, and I considered prudence required it to be avoided, notwithstanding the presence of the lime and soda.

The following is the manner of making the experiment:

I raised the water-bath to the desired temperature and maintained it constant as nearly as possible for exactly an hour; in general, the variations did not exceed $\frac{1}{20}°$. During this time I made a vacuum in the boiler by means of the tube Q, so that the pressure of the air therein did not exceed one millimetre of mercury; this done, I closed the cock R' and opened R progressively. I left the boiler in communication with the vapor generator B about an hour when I closed cock R and opened R'. I made by means of the Carré machine the vacuum very slowly in the absorbent tubes. When the pressure was not more than 3·5 centimetres of mercury, I interrupted, by manipulating the cocks, the communication of the apparatus with the pumps, and I allowed to enter very slowly the air purified by passing through the tubes T'. Equilibrium having been established with the atmosphere, I re-made the vacuum—always to 3·5 centimetres—and allowed the air to reënter, and so on; in every experiment I made, the air was let in four times, and consequently the vacuum was made five times.

The quantity of air thus remaining in the boiler is negligable. If, in fact, there be admitted that in an approximate calculation the law of Mariotte, and the law of the mixture of gases, can be applied to the vapor and to the air, the successive weights of vapor π, π_1, π_2, etc., contained in the boiler will be proportional to the successive pressures h, h_1, h_2, etc., of this vapor. The ratio of one of these pressures to the preceding being the ratio to the atmospheric pressure of the pressure remaining in the apparatus when the communication with the pump is interrupted; that is to say, $\frac{3·5}{76}$ or about one-twentieth, we should have

$$\frac{\pi_2}{\pi} = \frac{\pi_2}{\pi_1} = \frac{\pi_3}{\pi_2} = \frac{\pi_4}{\pi_3} = \frac{1}{20} \text{ and } \frac{\pi_4}{\pi} = \left(\frac{1}{20}\right)4 = \frac{1}{160000}$$

a quantity absolutely negligable.

Gauging.—The principal difficulty of these experiments is in the gauging of the capacity A. Two processes have been followed for that purpose.

(1) The determination of the mass of the distilled water

that fills the boiler at the temperature of 30°, which was the temperature of the experiments.

(2) The determination of the mass of pure carbonic acid contained therein under known conditions of pressure and temperature.

Gauging with Water.—The cover of the boiler is lifted and about 500 cubic centimetres of distilled water are put therein, then the cover is replaced and the water is boiled for a considerable time, the evacuating tube previously plunged into the water being maintained hot. The boiler is thus filled in the same manner as a thermometer. At the end of about an hour the whole apparatus is raised to the temperature of 30°, when the two cocks are opened. The cover is then cautiously removed and the water, taken out by a pipette, is received in a vessel previously tared. The sides are carefully dried by absorbing paper tared with the vessel, and the vessel and the paper are placed upon the scales. Two successive operations thus gave 1136·50 and 1137·13 cubic centimetres: they are the largest numbers obtained. As the sole errors that can be made arise from bubbles of air in the interior, or from a leak of water, and would consequently be errors of deficiency, the largest determinations must be considered as the nearest exact.

I have taken for the value of the volume the mean of the two preceding determinations, namely 1136·90 cubic centimetres.

Gauging with Carbonic Acid.—The carbonic acid, which should be perfectly pure, cannot be obtained by the ordinary processes as they always furnish it with a mixture of air. It was produced by the reaction of a solution of pure carbonate of soda freed of air, on pure sulphuric acid spread out and also freed of air. The solution of carbonate of soda, contained in a balloon, fell drop by drop, by means of a siphon fitted with a cock, into a large balloon containing the sulphuric acid. The two ends of the siphon were drawn out and recurved in such a manner that each of the two liquids could be boiled without causing it to prime. The carbonic acid produced passes first into a small balloon containing a little sulphuric acid for absorbing the water

vaporized during the boiling of the extended sulphuric acid, thence the gas passes into a vessel through sulphuric acid, and traverses four tubes of sulphuric pumice. The apparatus can operate about ten hours without need of renewing the liquids. All the evacuating tubes were cut true and level with the stoppers, so that they had no reëntering angles. I assured myself that a litre of carbonic acid contained at the moment of the trial only about thirty cubic millimetres of gas not absorbable by the potassa, which gas was probably hydrogen derived from the action of the sulphuric acid upon some traces of organic matter.

I allowed the gas to pass freely during six or seven hours into the boiler with a moderate speed, at the end of which time it contained on leaving the apparatus only the traces of other gas just described. I now closed the receiving cock and left the interior of the apparatus for some instants in communication with the atmosphere by means of a long tube filled with carbonic acid; then I closed the second cock and operated exactly the same as for density of vapor.

The absorbent tubes employed were four tubes of caustic potash, one tube of lime mixed with some soda, one tube of sulphuric pumice, and two tubes of phosphoric acid.

The following are the results given by two experiments:

Temperature. Degrees	*Weight of Acid Absorbed.* Grams.	*Volume.* Cubic Centimetres.
30·92	1·9930	1136·13
30·90	1·9928	1136·05

Mean, 1136·09 cubic centimetres.

a value very near that which I had found in operating with water, because the boiler having been compressed 0·012 centimetre,* its volume was diminished 0·9 cubic centimetre.

* The fraction of a millimetre was ascertained by the following artifice: I always made sure that the cover was parallel to the flange of the boiler by inserting a brass wedge between them all around so as to be in exact contact at the same distance from the back of the wedge. By doing this before and after the cover was screwed up, I obtained the thickness of the wedge at the edge of the cover for the two times, the difference between which, observed through a microscope, gave 0·012 centimetres for the value of the correction to be made.

The following are the results obtained for the specific volume of the saturated vapor of ether, in operating from 27° to 35°:

Temperature. Degrees.	*Specific Volume.*	*Observations.*
27·66	441·3	
28·60	423·9	
29·375	410·4	
29·72	405·1	
30·02	399·9	Double experiment.
31·50	377·2	
34·12	351·2	

In comparing these numbers with those I obtained by the first method, I have found a complete accordance. For example, the two first experiments made, one at 30° (first method), the other at 30°·02 (second method), gave, the one, 400 cubic centimetres, the other, 399·9 cubic centimetres, as the value of the specific volume.

This accordance gives an almost absolute certainty that the two methods do not contain any errors of system, for the apparatus were very different. In the one, the vapor is in contact with a glass surface, and, in the other, it is in contact with a golden surface. Had there been any sensible action by the surface, it is more than probable that it would have varied with the kind of surface. This is the most important justification of the two processes; it authorizes me to consider the numbers found as exact, and to apply them to the calculation of the mechanical equivalent of heat.

I stated at the commencement of this memoir, that Herwig thought a relation existed between the density of dry vapor and the density of saturated vapor. To show within what limits such an hypothesis is admissible, there suffices to cite the numbers deduced from my experiments for the value of the constant C in his formula

$$PV = CP_1 V_1 \sqrt{T}$$

or

$$A_1 = C A \sqrt{T}$$

in which $P_1 V_1 \Delta_1$ relate to the saturated vapor, and P, V, Δ relate to the dry vapor:

Name of Liquid.	*Temperature. Degrees.*	*C.*
Water,	68·2	0·0527
	88·6	0·0525
	98·1	0·0526
	99·1	0·0528
	99·6	0·0527
	101·5	0·0526
Ether,	30·0	0·0428
	57·9	0·0551
	85·5	0·0583
	110·5	0·0609

For the vapor of water the accordance is sufficient; but for ether C varies in an interval of 80° nearly half of its value at 30°.

CHAPTER II.

Determination of the Value of the Mechanical Equivalent of Heat.

By applying to a mixture of a liquid with its vapor the principle of the equivalence and the principle of Carnot, a relation is obtained which can also be deduced from the equation of Thomson: it is,

$$\frac{dT}{dt} L = \frac{1}{E} T (u' - u) \frac{dp}{dt}$$

This relation contains one independent variable t, the Centigrade temperature; four quantities, functions of this temperature, specific to the substance to which the relation is applied; L the heat of vaporization, u' and u the specific volumes of the vapor and of the liquid, p the pressure; the absolute temperature T, and a constant E, the mechanical equivalent of heat.

If T be supposed represented by the expression,

$$(273 + t), \quad \frac{dT}{dt}$$

becoming the unity, and if, for any particular value of t, there be introduced into the relation the system of values corresponding to

$$L, u', u \text{ and } \frac{dp}{dt}$$

it will contain no other unknown than E, and could be regarded as an equation permitting the determination of that quantity.

For a certain number of substances, and particularly for water, ether and the bisulphide of carbon,

$$L \text{ and } \frac{dp}{dt}$$

have been measured at different temperatures by Regnault and represented by empirical formulæ: u has been determined by other experimenters, and, finally, I have measured u' for these substances at certain temperatures; I am then able to calculate E, and the following are the results:

Name of Liquid.	*Temperature. Degrees.*	*Mechanical Equivalent of Heat.*	*Mean.*
Water,	68·20	424·6	423·95
	88·60	423·3	
	98·10	424·1	
	99·60	423·9	
	101·50	423·9	
Ether,	57·90	424·2	424·07
	85·50	424·0	
	110·50	424·0	
Bisulphide of carbon,	84·60	424·5	424·50

The accordance between the different numbers of this table is as satisfactory as possible, if there be considered that they are derived from numerical data obtained by three experimenters on different specimens of the substances, and that the presence of impurities often difficult to remove, escaping even chemical reactions, can profoundly modify the physical properties of substances.

In order to avoid this cause of error, I proposed to determine for the same specimen of the substance the four quantities

$$u, \frac{dp}{dt}, L \text{ and } u'$$

entering into the preceding relation. Endeavoring to obtain the value of the closest possible approximation to the mechanical equivalent of heat, I ought to place myself in

the best experimental conditions for diminishing as much as I could the errors that may have been committed in the determination of these quantities. It seemed to me that in the neighborhood of 30°, these measures could relatively be made without difficulty for ether; further, this substance is easily obtained and preserved pure; I have consequently chosen ether at 30°, and endeavored to obtain as exactly as possible the values of the four specific constants

$$u,\ \frac{dp}{dt},\ L \text{ and } u',$$

by operating on a single specimen of this substance.

I will now rapidly describe the methods employed, and then present combined under a single heading, the interpretation of the different results obtained.

Purification of the Ether.—Two litres of purified ether were placed during two months in contact with sodium, then, after all disengagement of gas had ceased, I carefully distilled this liquid in contact with newly cut sodium, and thus obtained about 700 cubic centimetres of a liquid the whole of which distilled rigorously at the same temperature, and in which the freshly cut sodium remained intact during ten days. At the end of that time it showed a slight alteration, due, doubtless, to the absorption of the aqueous vapor of the atmosphere by the anhydrous ether during the necessary manipulations of the experiment.

Measure of the Specific Volume of Liquid Ether and of its Coëfficient of Dilatation at 30°.—The method employed is derived from the method of the stem thermometer.

I constructed with a thermometric tube whose stem was graduated into equal lengths, a mercurial thermometer which I compared between 20° and 50° with a standard Baudin thermometer and afterwards with a thermometer that I had previously compared with an air thermometer. From these comparisons I deduced the value in degrees of each division, and constructed a trace by taking for abscissæ the numbers corresponding to each division of the thermometer for equal weights, and for ordinates the values of these divisions. The trace thus obtained was a straight

inclination to the axis of the divisions; I established by this process that the tube was regularly conical. In applying the method of least squares to the results found, I have obtained for the value of one division in degrees the formula

$$x = 0{\cdot}6425 + (120 - n)\, 0{\cdot}00034$$

n being the division read.

The weight of mercury contained in the reservoir and in the stem up to division 57, was 22·6090 grams, the weighing being done in a manner that rendered it certain within 0·0003 gram; the volume of that part at 0° was then 1·67166 cubic centimetres, the first five figures being exact, and the volume of division 120, 0·0001977 cubic centimetres. I had supposed the coëfficient of the dilatation of the glass equal to 0·000025; but in order to assure myself of its accuracy, I weighed a column of mercury comprising fifty divisions and found 0·0099 gram to nearly one-tenth of a milligram, then, as this weight, calculated according to the data above given, should have been between 0·0100 and 0·0099 gram, the agreement was satisfactory.

This gauging done, I emptied the mercury out of the thermometer and introduced the ether, after which I compared the thermometer anew with the standard. From this comparison I have deduced the coëfficient of dilatation between 29° and 31°, and find it 0·0017524. The thermometer filled with ether was weighed, then emptied, refilled and weighed again. The two weights of the contained ether were 1·2466 and 1·1755 grams, which give for the density the values 0·7035 and 0·7025; the mean of these determinations, 0·7030, has been taken for the value of the density. The specific volume is 1·422 cubic centimetres.

Measure of $\frac{dp}{dt}$.—Two methods have been employed to measure

$$\frac{dp}{dt}$$

(1) that which consists in measuring the tension of vapor p at different temperatures for the purpose of representing

empirically the value of p by a formula, and to deduce from it the first differential coëfficient

$$\frac{dp}{dt}$$

(2) a particular method allowing the direct determination of

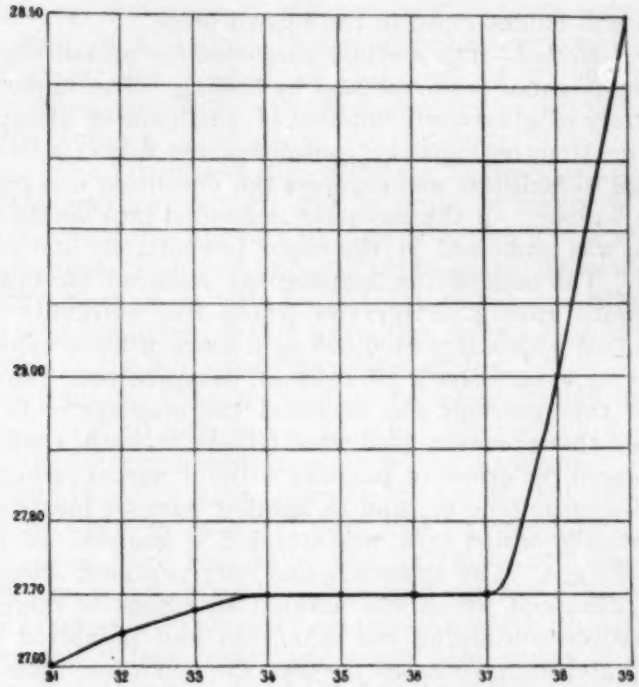
$$\frac{dp}{dt}$$

which will be described in the second place.

First Method.—The method employed for measuring the tension of vapor is the method by boiling. The apparatus —entirely of glass—is composed of a balloon of about 100 cubic centimetres capacity, containing the ether; a Gernez gas bell to facilitate and regulate the ebullition was placed in the balloon. A thermometer A divided into tenths of a degree was immersed in the vapor immediately above the liquid. The neck of the balloon was soldered laterally to an upward Liebig refrigerator whose free extremity communicated with a large balloon of a score of litres capacity placed in a water-bath of constant temperature. To one part of this reservoir was attached the manometer of the Joly air thermometer, graduated on ice in such a manner as to avoid the errors of parallax without necessitating the use of a cathetometer; and to another part, by means of a hermetically sealed tube, was attached a machine for rarefying the gas. The apparatus had only two cork stoppers, the tightness of which was assured by means of mercury. The balloon containing the ether was half immersed in a large water-bath, so as to prevent the radiation upon the thermometer of the flame that had been placed directly beneath the balloon. The temperature of the thermometer A depended upon three quantities: the radiation R of the water-bath upon the thermometer, the radiation R' of the thermometer on external cooler objects, and the heating or cooling of the thermometer by the action of the vapor into which it was immersed. If R is less than R', the cooling of the thermometer is compensated, at least in part, by the liquefaction of the vapor; if, on the contrary, R is greater

than R', the thermometer can only be cooled by the convection of the vapor, a much less powerful action than liquefaction. To show how the temperature of the thermometer A varies with that of the water-bath, I placed a thermometer B in the latter and observed the two instruments simultaneously while increasing, from five minutes to five minutes, the temperature of the water-bath 1°. The trace (*Fig. 7*)

Fig. 7.



obtained by taking for abscissæ the indications of B, and for ordinates those of A, shows a horizontal part corresponding to a variation of about 4° of the temperature of B; this is the constant temperature that has been taken for the boiling temperature; the trace, previous to that part very little inclined by reason of the reheating power of the liquefaction, rises rapidly afterwards because the effect of the radiation is no longer counterbalanced by that

of the convection. The following are the numbers obtained during an experiment:

B, .	31	32	33	34	35	36	37	38	39
A, .	27·60	27·65	27·68	27·70	27·70	27·70	27·70	28·00	28·50

For all the measures I arranged the conditions to be such that the thermometer *A* marked the exact temperature of boiling; in this case, for example, so that the temperature of the water-bath was comprised between 35° and 36°.

The experiments, made with these precautions, gave the following results:

FIRST GROUP.

Temperature. Degrees.	*Pressures in Centimetres of Mercury.*
26·41	56·644
27·51	58·146
28·31	59·901
29·21	61·886
29·71	63·103
30·21	64·290
30·71	65·536
31·21	66·634
31·71	67·826
32·21	69·086

SECOND GROUP.

28·21	59·626
28·71	60·772
29·21	61·923
29·71	63·000
30·21	64·257
30.71	65·454
31·21	66·631
31·71	67·967

THIRD GROUP.

28·21	59·619
28·71	60·781
29·21	61·924
29.71	63·015
30·21	64·272
30·71	65·448
31·21	66·630
31·71	67·915

Each of these groups of measures was made with *new* ether, and the uniformity of the results, very remarkable in

the last two groups, shows the apparatus to have been thoroughly dried.

Second Method.—This method allows the determination to be separately made of the two terms of the relation

$$\frac{dp}{dt}$$

Imagine that we seek to measure the tension of the ether vapor at 30° with the apparatus just described under the head of "First Method," and that there was a slow reëntrance of air into this apparatus, the pressure would gradually increase and the temperature rise, so that these two quantities would be functions of the time.

Considering an infinitely small interval of time $d\theta$, we could write

$$dp = kd\theta$$

$$dt = k'd\theta$$

k and k' being the speeds

$$\frac{dp}{d\theta}$$

and

$$\frac{dt}{d\theta}$$

of the variation of the pressure and of the temperature. As t is only a function of p,

$$\frac{dp}{dt} = \frac{k}{k'}$$

If experiment showed that these speeds vary very slowly, we could, in place of infinitely small variations, consider variations finite but very small; that is to say, write

$$\Delta p = k\Delta\theta, \qquad \Delta t = k'\Delta\theta, \qquad (1)$$

and the relation

$$\frac{k}{k'}$$

could be directly measured. Let θ_1 be the time necessary for the pressure to increase to 0·1 centimetre; θ_2 that which

corresponds to a rise of temperature of 0°·1; we should have

$$0{\cdot}1 = k\theta_1, \qquad 0{\cdot}1 = k'\theta_2,$$

whence

$$k\theta_1 = k'\theta_2$$

and

$$\frac{k}{k'} = \frac{\theta_2}{\theta_1} = \frac{dp}{dt}$$

we have then to measure only the relation of two times, a quantity independent of the chronometer employed.

The reëntrance of the air that I employed in the apparatus, was effected by means of a very fine capillary tube. I first investigated how the coëfficients k and k' varied; that is to say,

$$\frac{1}{\theta_1}$$

and

$$\frac{1}{\theta_2}$$

for successive intervals of time, and I am convinced that we can rigorously consider k and k' as constants and apply the equations (1) for considerable variations of pressure.

The following are the results of an experiment:

Manometer (mm.),	65	64	63	62	61	60	59	58	57
Times (seconds),	155	238	324	408	492	576	662	745	829
Differences,	83	86	84	84	84	86	83	84	
Mean of the differences,									84·25
Thermometer (degrees),				29·40	29·50	29·60	29·70	29·80	
Times (seconds),				315	518	708	904	1,099	
Differences,				197	196	196	195		
Mean of the differences,									196
Mean temperature,									29·60

The above show that for variations of θ_1 corresponding to a low maximum of eight millimetres of the manometer, the conditions are as previously stated.

We may write, therefore, that at 29°·60, the mean temperature observed, we have*

$$\frac{dp}{dt} = \frac{\theta_2}{\theta_1} = \frac{196}{84{\cdot}25}$$

The indications of the manometer are instantaneous, those of the thermometer are not; but, the temperature varying with regularity, there would be established a permanent *régime* in which the retardation of the instrument would be constant. Further, we can control the value of this retardation, because in diminishing the speed of the reëntrance of the air into the apparatus, we can vary the temperature as slowly as we wish. After having established the variations of temperature, we need not give them any further attention.

The method consists, then, in measuring with a chronometer arranged for making dots, or any other apparatus capable of registering time, the intervals necessary for obtaining, on the one hand, an increase of pressure of 0·1 centimetre of mercury, and, on the other hand, a rise of temperature of 0°·1; the quotient of these two times gives

$$\frac{dp}{dt}$$

expressed in centimetres of mercury.

The advantage of this method consists in only being obliged to detect the instant when a mercurial column corresponds with a unit division, and, consequently, of being able to dispense with estimating fractions of a division which is always a delicate matter: the thermometer and the manometer used in these experiments being graduated on the stem, made this detection easy. The precision is in one sense unlimited, because in diminishing the speed of the reëntrance of the air, the time for making the observation is increased; that is to say, the two terms of the relation

$$\frac{dp}{dt}.$$

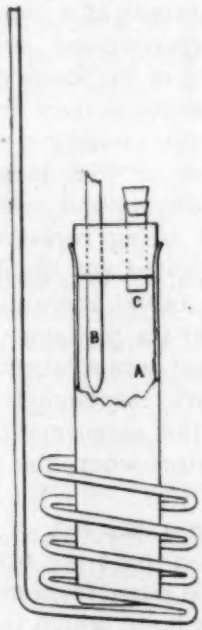
* I do not speak of ordinary corrections necessary to be additionally made.

The following are the results obtained in operating between 29° and 31°:

Temperature (degrees), . .	29·01	29·51	29·61	29·91	30·11	30·21	31·01
$\frac{dp}{dt}$ (cm. of mercury), . .	2·2770	2·3171	2·3252	2·3505	2·3677	2·3757	2·4422

Measure of the Heat of Vaporization.—The method employed for measuring the latent heat of vaporization, is one

Fig. 8.



of those described by Berthelot in his *Essay on Chemical Mechanics.*

It consists in measuring the fall of temperature produced by the vaporization under a gaseous current of a determined quantity of liquid.

A laboratory tube *A* (*Fig. 8*), of thin brass containing the liquid, is placed in the calorimeter; the dry air which produces the vaporization penetrates into the apparatus through a glass tube *B*, passed very tightly through the cork stopper closing the tube *A*; it passes out at about two

thirds of the height of the laboratory tube through a brass coil of about one metre length wound around the tube *A* and finally debouching into the atmosphere outside of the calorimeter. The cork of the large tube *C* is itself closed by a small cork.

The process of the operation is as follows:

The calorimeter is allowed to remain from three to four hours in a chamber heated to about 30°, the water of the enciente being maintained at a temperature between 33° and 35°: in the experimental conditions under which I operated, the heating of the water due to the excess of the temperature of the enceinte over that of the calorimeter nearly compensated the cooling due to the vaporization. At the end of the three or four hours there is introduced into the laboratory tube a phial containing a known mass of ether, the tube *B* being replaced. The water of the calorimeter is now agitated and the dry air passed through; the latter is dried in tubes containing sulphuric pumice, and is heated to 30° by its passage through a coil of lead pipe maintained at that temperature. At the end of half an hour the calorimetric thermometer is observed, and we wait, to commence the experiment, some ten or fifteen minutes, in order to start when the permanent regimen is established.

The stopper is then taken out of tube *C*, and the phial broken by a sharp iron rod; the tube is quickly reclosed, and the thermometer is noted from minute to minute during about a quarter of an hour, which is the time required for an experiment; and it is also noted for fifteen minutes afterwards.

The calculation for the correction has been made according to the directions given by Berthelot. As to that which regards the heat of vaporization, it has been made in the following manner:

Let *H* be the weight of the calorimeter water, *M* the mass of ether vaporized, t_1 and t_2 the initial and final temperatures, t the temperature at any instant whatever; $\vdash$ the reheating resulting from external action. Further, let dm be an infinitesimal mass of ether, whose vaporization corresponds to a

variation dt of temperature and to a correction $d\theta$; we would then have

$$-H\,dt - H d\theta = L\,dm$$

or

$$-\frac{dt}{L} = \frac{dm}{H} + \frac{d\theta}{L}$$

For any given experiment, m, t and θ are functions of the time, L is the same because it is a function of t; we could then integrate the preceding relation within the limits of an experiment and write

$$-\int_{t_1}^{t_2} \frac{dt}{L} = \frac{\int_0^M dm}{H} + \frac{\int_0^\theta d\theta}{L_1}$$

replacing in the second term of the second member, L by its mean value L_1 during an experiment, a permissible approximation, this term being a correction.

In the first member we do not know the relation between L and t; but Regnault has shown that for ether this quantity can be represented by the formula

$$L = 94{\cdot}00 - 0{\cdot}07901\ t - 0{\cdot}0008514\ t^2.$$

There can be admitted, with what seems a sufficient approximation when the smallness of the coëfficient of the term in t^2 is considered, that for an internal of from 4° to 6° in the neighborhood of 30°, there can be put

$$L = a + bt,$$

whence the expression becomes

$$-\int_1^{t_2} \frac{dt}{a+bt} = \frac{\int_0^M dm}{H} + \frac{\int_0^\theta d\theta}{L_1}$$

or

$$\frac{1}{b} L\left(\frac{a+bt_1}{a+bt_2}\right) = \frac{M}{H} + \frac{\theta}{L_1}$$

In developing the logarithm in series following the increasing powers of

$$\frac{b}{a}$$

and stopping after the term in

$$\frac{b^2}{a_2}$$

we have

$$\frac{1}{a}(t_1 - t_2)\left[1 - \frac{1}{2}\frac{b}{a}(t_2 + t_1)\right] = \frac{P}{II} + \frac{\theta}{L_1}.$$

In grouping the experiments two and two, we shall have as many systems of two equations as of groups of experiments, and as many values of the quantities

$$a \text{ and } \frac{b}{a}$$

that is to say, of a and b.

The following are the results obtained:

Nos. of the Groups.	a	$-\frac{b}{a}$	$-b$
1, ...	95·035	0·0013521	0·1285
2, ...	95·200	0·0013655	0·1300
3, ...	95·285	0·0013749	0·1310
4, ...	95·360	0·0013528	0·1290
5, ...	95·066	0·0013695	0.1302

Interpretation of the Results.—Before showing the manner in which I have interpreted the results obtained, I think there should be briefly recalled the principles of the theory of errors which I have adopted.

When by a succession of measures freed of systematic errors, we have obtained different values of a quantity function of a variable, it is often interesting to represent that quantity by an empirical function of that variable, of the form

$$A + B_x + C_{x^2},$$

for example.

The coëfficients A, B and C are determined in such a

manner that the sum of the squares of the residues ε, calculated after the m relations

$$\varepsilon_1 = N_1 - (A + B_{x_1} + C_{x_1^2})$$

$$\varepsilon_2 = N_2 - (A + B_{x_2} + C_{x_2^2})$$

is a minimum (N_1, N_2, etc., being the results of experiments.)

The mean error of a determination is

$$\sqrt{\frac{\Sigma(\varepsilon^2)}{m}}$$

and the probable error is about two-thirds of that, namely,

$$\frac{2}{3}\sqrt{\frac{\Sigma(\varepsilon^2)}{m}}$$

If we have a quantity M, function of several others

$$M = F(P, Q, R, \text{etc.}),$$

and if p, q, r represent the mean errors of P, Q, R, the mean error of M will be

$$\sqrt{\left(\frac{dM}{dP}p\right)^2 + \left(\frac{dM}{dQ}q\right)^2 + \left(\frac{dM}{dR}r\right)^2 + etc.}$$

the probable error being still two-thirds of the mean error.

I will now pass in review the different determinations made, giving for each the calculated formulæ and the respective mean errors.

Value of u.—The two values 0·7035 and 0·7025 have been found for the density of ether at 30°; the mean is 0·7030, the mean error being 0·0005.

The value 0·7038 found by Isidore Pierre, is a little but not much greater.

The specific volume

$$u \text{ is } \frac{1}{d} = \frac{1}{0{\cdot}703} = 1{\cdot}422 \text{ cc.}$$

and the mean error.

$$\partial u = \frac{\partial d}{d^2} = 0{\cdot}001$$

The coëfficient of dilatation, which I have found equal to

0·0017524, is intermediate between the following numbers given by different experimenters.

0·0017531 (Is. Pierre).
0·0017668 (Kopp).
0·0017421 (Hirn).

I have taken as the value of u, τ being the excess above 30° of the temperature expressed in degrees,

$$u = 1^{cc}\cdot422 + 1\cdot422 \times 0\cdot00175\ \tau,$$

whence

$$u = 1^{cc}\cdot422 + 0\cdot00249\ \tau \text{ (mean error } 0\cdot001).$$

Value of $\frac{dp}{dt}$

First Method.—I have put

$$p = A + B\tau + C\tau^2,$$

and calculated A, B, C, by the method of least squares with the aid of each of the three groups of measures effected, as previously shown.

I have thus found:

	A. Centimetres.	*B.*	*C.*
First group, ...	63·722	2·3593	0·04
Second group, ...	63·684	2·3599	0·04
Third group, ...	—	2·3587	0·04
Means, ...	—	2·3593	0·04

The mean error on B has been calculated at 0·0005. The values given by Regnault are:

$$A = 63\cdot5035 \qquad B = 2\cdot3548$$

The difference on the value of B is, as shown, very slight.

Second Method.—In putting

$$\frac{dp}{dt} = B + C\tau$$

I have found

$$B' = 2\cdot3584 \qquad C' = 0\cdot0834$$

Calculating the mean error of the determinations, we find

0·0005.

The value of C' is, as it ought to be, twice the value of C.

The value taken for

$$\frac{dp}{dt}$$

is, in centimetres of mercury,

$$\frac{dp}{dt} = 2{\cdot}3584 + 0{\cdot}0834\ \tau$$

or, in grams per square centimetre,

$$\frac{dp}{dt} = 32{\cdot}0648 + 1{\cdot}1359\ \tau \text{ (mean error } 0{\cdot}007).$$

Value of L.—In introducing τ into the formula

$$L = a + bt,$$

we have the following relation

$$L = a' + b\tau\ (a' = a + 30\ b).$$

The values of a' thus determined are:

	a'	b
First group,	91·18	− 0·1285
Second group,	91·30	− 0·1300
Third group,	91·35	− 0·1310
Fourth group,	91·49	− 0·1290
Fifth group,	91·16	− 0·1302

The calculation made has given for a' and b the values

$$a' = 91{\cdot}29, \qquad b = 0{\cdot}1297,$$

the mean error being 0·12.

The formula I have finally adopted is

$$L = 91{\cdot}29 - 0{\cdot}1297\ \tau. \qquad (1)$$

Regnault gives

$$L = 94{\cdot}00 - 0{\cdot}07901\ t - 0.0008514\ t^2,$$

which corresponds for a formula in τ, to

$$L = 91{\cdot}395 - 0{\cdot}13109\ \tau - 0{\cdot}0008514\ \tau^2, \qquad (2)$$

regard being had to the mean error 0·12, these two formulæ can be considered as concordant.

Value of μ.—The two methods employed being sufficiently concordant, the results found by the application of each have been employed without distinction of origin for obtaining the value of μ.

I have consequently based the calculation on the results of the first method obtained for the temperatures

$$28°{\cdot}4, \qquad 30°{\cdot}0 \qquad 31°{\cdot}7, \qquad 31°{\cdot}9,$$

and on those of the second corresponding to

$$28°{\cdot}6, \quad 29°{\cdot}375, \quad 29°{\cdot}72, \quad 30°{\cdot}02, \text{ and } 31°{\cdot}50.$$

The two other results obtained in that last series, the one at 27°·66, the other at 34°·12, should be omitted as too far removed from the temperature of 30°. It would have been necessary to use a formula in τ^3 in order to represent them.

The formula obtained is the following:

$$u = 400{\cdot}42 - 15{\cdot}7394\,\tau + 0{\cdot}539\,\tau^2$$

The following table shows in comparison the numbers resulting from experiment and from calculation. The numbers in heavy type were obtained by the first method.

Temperature.	*Found.*	*Calculated.*	*Difference.*
28·40	**426·20**	426·08	**+ 0·1**
28·60	423·90	423·51	+ 0·4
29·375	410·40	410·48	— 0·1
22·72	405·10	404·87	+ 0·2
30·00	**400·00**	400·42	**— 0·4**
30·02	399·90	400·11	— 0·2
31·50	377·20	377·02	+ 0·2
31·70	**375·10**	375·22	**— 0·1**
31·90	**373·00**	372·56	**+ 0·4**

The mean error is 0·28.

Value of E.—There only remains to introduce into the formula

$$E = \frac{T\,(u' - u)\,\frac{dp}{dt}}{L}$$

the preceding results in order to obtain the value of E, which will be expressed in grams-centimetres, corresponding consequently to a small calorie. If, in the preceding formulæ, we make

$$\tau = 0$$

$$E = \frac{303\,(400{\cdot}42 - 1{\cdot}42)\,32{\cdot}0648}{91{\cdot}29} = 42463$$

The mean error on the value of E is about 0·5: the probable error will consequently be 0·34.

If, in the relation there be introduced the formulæ themselves which represent

$$u, u', \frac{dp}{dt} \text{ and } L$$

in function of τ, there is obtained for representing E, a function of τ

$$E = \frac{(303 + \tau)(400{\cdot}42 - 15{\cdot}7394\,\tau + 0{\cdot}539\,\tau^2 - 1{\cdot}42 - 0{\cdot}0025\,\tau)(32{\cdot}0648 + 1{\cdot}1359\,\tau)}{91{\cdot}29 - 0{\cdot}1297\,\tau}$$

I have calculated the values of that function for several values of τ, and found them to vary very slowly.

Value of τ	*Value of* E.
− 1·0	42429
− 0·2	42458
− 0·1	42461
0·0	42463
+ 0·1	42467
+ 0·2	42470
+ 1·0	42493

This is, I believe, an important verification of the final result. It is evident that there cannot be found for E a quantity independent of τ, but the variation is very slight here, for it is sensibly represented by

$$E = 42463 + 30\,\tau.$$

From $\tau = -0{\cdot}2$ to $\tau = 0{\cdot}2$ it is only 12, while the probable error of a determination is 34.

Finally, the value of the mechanical equivalent of heat found in the last place, very near the numbers deduced from the experiments on water, previously given, is in kilogrammetres

424·63

with a probable error of 0·34.

Seen and approved:
Paris, the 7th October, 1887.
E. HÉBERT,
Dean of the Faculty of Sciences.

PROCEEDINGS

OF THE

CHEMICAL SECTION

OF THE

FRANKLIN INSTITUTE.

[*Stated meeting held Tuesday, January 19, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 19, 1892.

Dr. W. H. WAHL, President, in the chair.

The election of officers, which was postponed from the December meeting, was first taken up, and on motion the Secretary was directed to cast the vote of the Section for all the nominees.

Mr. Chas. S. Boyer read a paper giving the results of a number of analyses made by him of egg yolk. It was referred for publication in the *Journal.*

Mr. H. Pemberton, Jr., followed with two communications, one on gas analysis, including the description of a new form of gas measuring apparatus, which simplified the reduction of volumes to the standard conditions of temperature and pressure. The second paper was a description of a rapid method for the determination of carbonic acid gas. Both were referred for publication in the *Journal.*

Dr. Wahl then presented a paper presenting a new interpretation of the chemical reactions which take place in the operation by which aluminium is deposited in the electrolytic process of manufacture. The paper included a complete description of the process as it is at present carried out, and was followed by the explanation in detail of the views entertained by the author on this interesting subject. Dr. Wahl also exhibited a number of aluminium articles recently turned out by the Pittsburgh Reduction Company. The paper was referred for publication, and after some discussion upon it, and an inspection of the exhibit, the Section adjourned.

WM. C. DAY, *Secretary.*

THE SPECIFIC HEAT OF ALUMINIUM.

BY J. W. RICHARDS, Lehigh University.

[*Read at the stated meeting of the Chemical Section, held December 15, 1891.*]

The determinations of the specific heat of aluminium are but few in number, and yet vary widely.

As soon as Sainte-Claire Deville had obtained a button of aluminium, in 1855, his friend Regnault importuned him for a specimen with which to determine its specific heat, and although Deville knew that the metal he had made was far from pure, yet he yielded to Regnault's request and furnished him with three small pieces, which analyzed:

Silicon,	2·87
Iron,	2·40
Copper,	6·38
Lead,	traces
Aluminium,	88·35

Regnault determined the mean specific heat of this metal between 25° and 97° to be 0·2056. He attempted to calculate approximately the specific heat of pure aluminium by allowing for the impurities present. In doing this he assumed the specific heat of silicon to be 0·1425, it not having been then determined, and his calculation gave him 0·2181 as the number for pure aluminium. Had he, however, used what we now know to be the specific heat of silicon, 0·21, he would have calculated 0·2200 as the specific heat of pure aluminium between 25° and 97°.

A year later Regnault obtained aluminium about 97 per cent. pure. He obtained for this, between 14° and 97°, 0·2122. Allowing for the impurities present, he calculated 0·2143 as the probable number for pure aluminium.

It may be remarked in passing, as a curious fact, that Regnault treats these mean values as if they were invariable constants, independent of the range of temperature through which they were determined.

Following Regnault came Kopp, who in 1863 made determinations with ordinary Parisian aluminium. He

obtained 0·2020 as the mean value between 20° and 52°. However, no analysis is given of the metal used, and from a consideration of the way in which Kopp experimented, and the degree of accuracy which was possible in his experiments, it is evident that his results are of very little value. For instance, four determinations gave him

0·1970
0·2000
0·2070
0·2020

from which he simply deduces 0·2020 as an average value.

In 1882, Professor Mallet made some absolutely pure aluminium for his researches on the atomic weight, and he determined its mean specific heat between 0° and 100°, by means of a Bunsen ice calorimeter, to be 0·2253. Since no impurity was present in the metal, this determination is free from one of the sources of error of the previous ones.

More recently, Naccari, the noted Italian physicist, states that he obtains for the true specific heat of aluminium at various temperatures the following values:

18°	50°	100°	200°	300°
0·2135	0·2164	0·2211	0·2306	0·2401

It will be noticed that these values indicate that the specific heat increases 0·0095 per 100°, and lead to the formulæ:

$$S = 0{\cdot}2116 + {\cdot}000095\, t$$
$$Sm = 0{\cdot}2116 + {\cdot}0000475\,(t_1 + t_2)$$

in which 0·2116 is the true specific heat at 0°. The mean between 0° and 100° would be 0·2164, comparing well with Regnault's results, but much lower than Mallet's. It is not stated what was the purity of the metal used by Naccari.

The question which the writer set out to solve presented itself to him in this way: Who is nearest the truth, Reg nault and Naccari, or Mallet?

I obtained some aluminium made by the Hall process, which analyzed:

Silicon,	0·07
Iron,	trace
Aluminium,	99·93

Since the atomic weight of silicon is almost identical with that of aluminium, it was felt safe to neglect the influence of the 0·07 per cent. present.

Three methods of procedure were used. First, a large weight of aluminium (100–200 grms.) was put into an empty calorimeter, whose water equivalent had been accurately determined by experiment, and allowed to stand several hours. When the temperature was nearly constant, a known weight of water at a higher temperature was run in, and the total loss of heat calculated from the observations. This method gave mean specific heats between about 16° and 22°. Secondly, the aluminium was suspended in steam and dropped into the water in a calorimeter. This gave values from 20° to 100°. Thirdly, two exactly similar calorimeters were used. The aluminium and a platinum ball weighing fifty-two grammes were placed on a platinum support and heated together either in an air bath to 120°, or in a small furnace up to 400°, 500° and 600°. The platinum ball was dropped into one calorimeter and the lump of aluminium into another. From the heat given out by the platinum its temperature was calculated, and assuming that the aluminium had been at the same temperature, I had the data for calculating its mean specific heat.

The third method gave the most concordant results. The first method was used for such a small range of temperature that the experimental errors were large. The second method was defective in default of suitable apparatus to secure the instant transfer of the metal from the steam into the calorimeter. The third method had the advantage, that since the platinum and aluminium were taken out of the furnace together and were dropped almost simultaneously into the calorimeters, it could fairly be assumed that they would cool about the same amount in the two or three seconds during which they were exposed to the air.

The writer has made two experiments by the first method, five by the second and sixteen by the third. Selecting those experiments, which were experimentally the nearest to perfect ones, and correlating the data by the

method of least squares, the following formulæ were arrived at:

$$Sm = 0{\cdot}2220 + 0{\cdot}00005\,(t_1 + t_2)$$
$$S = 0{\cdot}2220 + 0{\cdot}0001\,t$$

in which 0·2220 is the true specific heat at 0° C.

From these formulæ the following values will be shown:

Temperature.	*True Specific Heat.*	*Range of Temperature.*	*Mean Specific Heat.*
0°	0·2220	0° — 100°	0·2270
20°	0·2240		
100°	0·2320		
		0° — 625° (melting point)	0·2533
625° (melting point)	0·2845		
		Total caloric capacity to the melting point,	. . 158·3

It is seen that the author's results confirm Mallet's determination, as far as the true specific heat is concerned, and agree closely with Naccari's observation of its rate of increase with the temperature.

PROCEEDINGS
OF THE
ELECTRICAL SECTION
OF THE
FRANKLIN INSTITUTE.

[*Stated meeting, held Tuesday, January 5, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 5, 1892.

Prof. EDWIN J. HOUSTON, President, in the chair.

Present, thirty-six members and visitors.

The minutes of the previous meeting were read and approved.

One nomination to membership was referred to the Committee on Admissions. The committee reported three elections since last meeting.

Mr. A. L. Church's resignation of membership was presented and accepted.

Mr. H. S. Hering gave a description of some types of recording volt- and ammeters, and suggested some new modifications.

Mr. W. S. Aldrich continued his remarks upon electro-magnetic machinery, with lantern illustrations.

Prof. Houston read a paper on "An Early Conception of Magnetic Field." Referred for publication.

The meeting then adjourned. L. F. RONDINELLA, *Secretary.*

THE ELECTRIC RAILWAY AT BUDA PESTH.

BY H. W. BARTOL.

[*Abstract of paper read at the stated meeting, held December 1, 1891.*]

Ever since electricity has become not only a possibility for traction purposes, but has in fact come largely into use for that purpose, efforts have been made to arrive at some satisfactory system for use in cities whereby the overhead wire could be dispensed with.

With the above intention, extensive experiments have been made with storage batteries and some few attempts made to supply the necessary current through a conduit, having an open slot somewhat similar to that used by the cable companies, a notable instance of which was the short piece of line laid in the city of Boston a few years since.

Repeated trials have shown that up to the present time there is no storage battery which can be used to advantage, and the battery experiment having failed, many had con-

cluded that we must adopt the trolley system or wait for further developments in electrical propulsion.

There have been several patents taken out for supplying the current through an underground conduit, with an arrangement whereby only a small portion of the conductor is charged at a time, the object being to prevent (what was supposed to be a very serious loss) leakage, but while experiments were being made in that direction in this country, actual practice on the other side of the ocean has shown that this is a danger more imaginary than real, and while we have been seeking to overcome this, Messrs. Siemens &

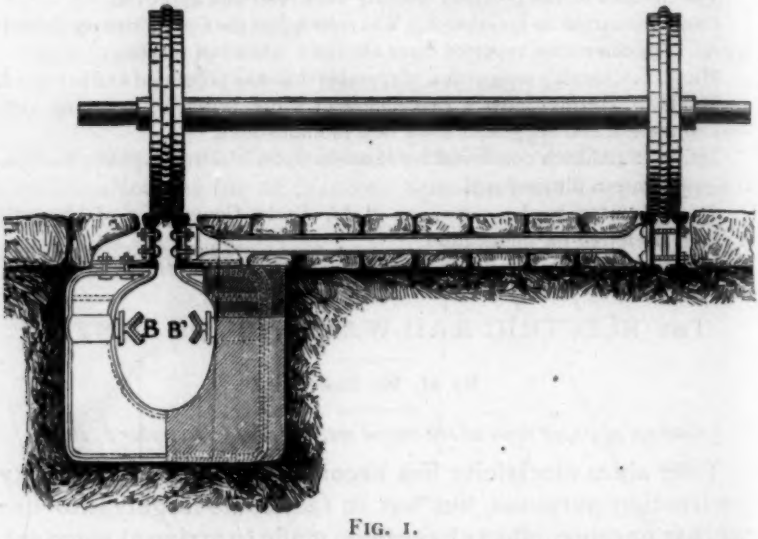


FIG. 1.

Halske, of Berlin, have built and have had in operation for over two years in Buda Pesth, a road which supplies the current through a conduit, and which it is now my intention to briefly describe.

By referring to *Fig. 1* you will see a conduit shown on the left, the slot being used as a groove for a flange of one of the wheels; *B* and *B'* are the conductors which supply the necessary current for driving the dynamo on the car. This conductor is made of angle iron properly insulated, and in it runs a trolley which makes contact with the two sides, viz: at *B* the current is received and at *B'* it is returned to the power station.

Fig. 2 represents a number of the iron frames in place and shows how the arrangements for switching are made.

Fig. 3 shows a truck and motor, in which it will be noticed they use a chain instead of gearing for reducing the speed and which it is claimed does away with a great deal of the noise.

The actual results obtained in Buda Pesth and the cost of building the road there are as follows: cost of road-bed, conduit, conductor, repaving, etc., $20,000 a mile. The voltage employed is 300, the ampères used in running the car after it is started, twenty-three; to start the car, however, when fully loaded, requires about eighty ampères. The weight of the car empty is about four and one-half tons, and its carrying capacity when full is forty people.

The heaviest grade in Buda Pesth is one and six-tenths per cent., but experiments on a four per cent. grade show that it requires an average of thirty-eight instead of twenty-three ampères to obtain the same speed.

We now come to some of the more practical considerations, namely: Is the road a success, and is the leakage such an item as to figure materially in the cost of operation? To the first of these questions the answer is unequivocally, Yes; to the second the answer is, that in dry weather the leakage is practically *nil*, and in wet weather on a line thirteen miles long it does not exceed three per cent., and in addition to this, is the fact that the friction of moving the car is so much less in wet weather than in dry that it actually requires less power at the power station notwithstanding the three per cent. leakage.

As the conduit is connected with the sewer at many points, no trouble is experienced from its filling with water, nor have they encountered any trouble in keeping the line free from snow, although the climate in Buda Pesth is fully as cold as that of Philadelphia.

The contact which takes the current from the conductor is a sliding one and of iron and the conduit between the iron frames is made of cement.

The speed allowed in Buda Pesth is ten miles an hour and in the suburbs eleven and one-half, which speed they

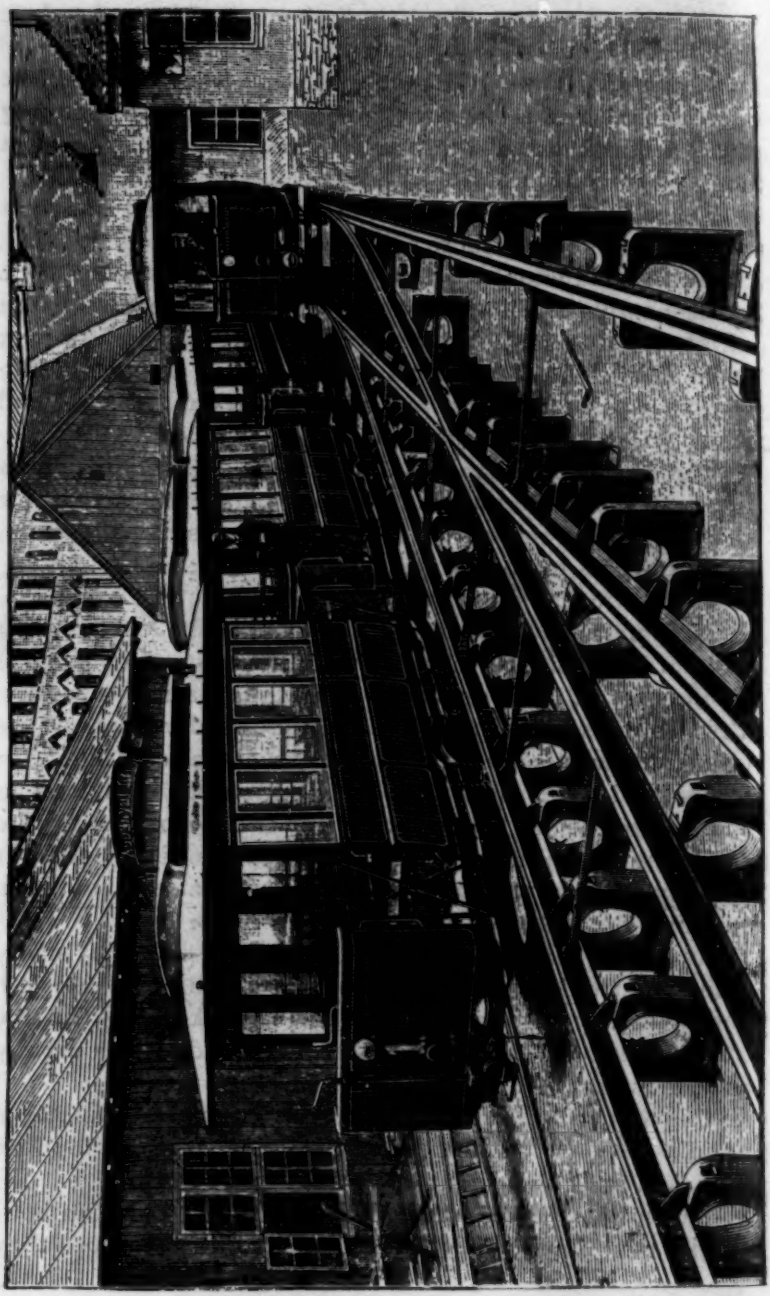


FIG. 2.

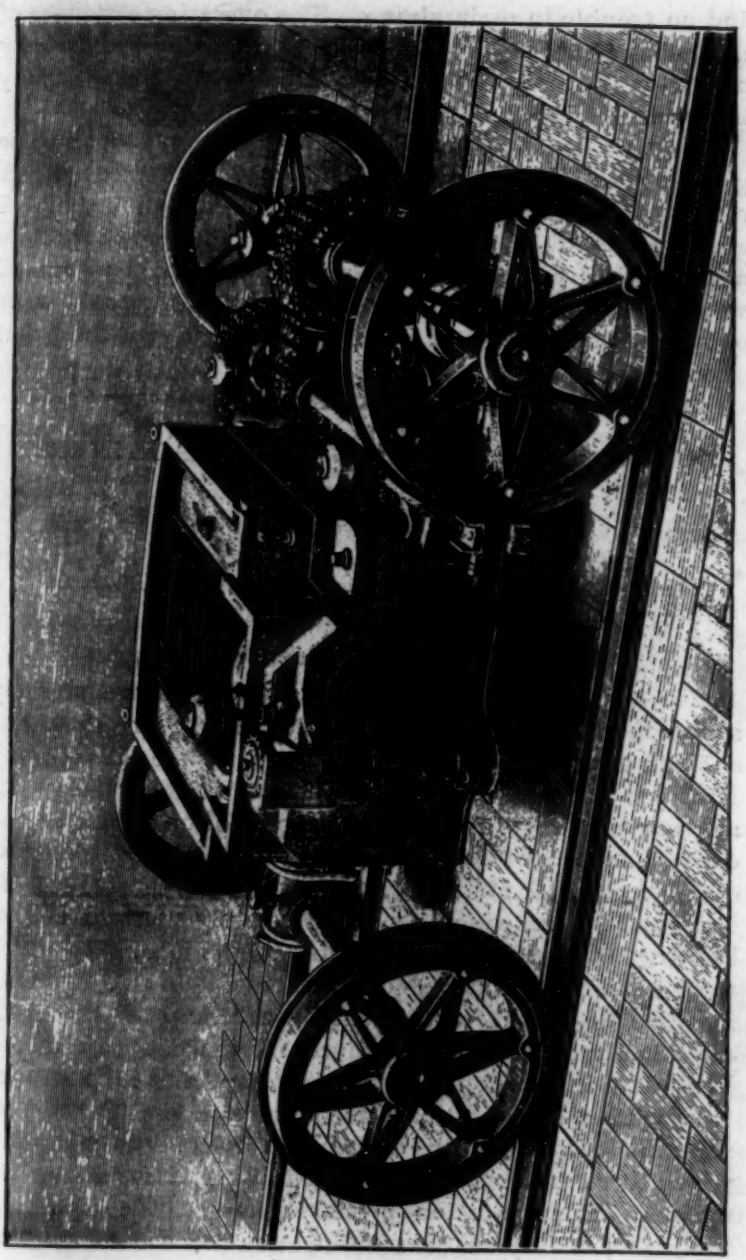


FIG. 3.

FIG. 2.

find no trouble in maintaining. The operating expenses of the company are lower than those of nearly every company using the trolley system in this country, and the company is paying dividends.

In conclusion, I might add that this system is soon to be given a practical test in this country, as a prominent railroad syndicate has undertaken to build six miles, and I am sure the public will agree with me in hoping it will be a success and a step in the direction of securing what all want, namely, a satisfactory system of rapid transit without the disadvantage of the overhead trolley or the great expense of the cable.

NOTES ON ELECTRO-MAGNETIC MACHINERY.

[FIRST PAPER.]

By Wm. S. Aldrich, M.E.,
Associate in Mechanical Engineering, Johns Hopkins University.

[*Read at the meeting of the Electrical Section held December 1, 1891.*]

The terms Machinery, Machines, Mechanisms are scarcely synonymous, though often so used. Early writers on the subject, among which the names of Monge, Carnot and Lanz are prominent, speak of mechanisms as means for altering or changing the direction of motion; such as the conversion of motion from continuous circular to reciprocating rectilinear motion. Ampère defined those mechanisms to be pure, which consisted entirely of rigid bodies, limiting, as it were, the definition to the means by which the motion was produced or transferred; and he defines a machine to be "an instrument by the help of which the direction and velocity of a given motion can be altered." Willis, in his *Principles of Mechanism*, follows closely, at first, with a classification based on comparative motion, subordinating the means and modes of communication by which these motions were obtained; but, later, making the mode of communication primary, and the comparative motion secondary in his classification of the elementary

combinations of pure mechanism. Rankine, in his *Machinery and Millwork*, adheres to Willis' later classification, but includes hydraulic connection as having a legitimate place among the means for the communication of motion in mechanisms. This marks a definite advance, for the means employed to communicate or transmit motion may be quite different, but the kinematic question remains the same—which is that of pure motion.

The Idea of the Kinematic Chain was brought out by Reuleaux, in his work on the *Kinematics of Machinery*, as the next step in the development of the science of machinery. He thus defines a mechanism to be "a closed kinematic chain, which is compound or simple, and consists of pairs of elements; these carry the envelopes for the motion which the parts in contact must be given, and by these envelopes all other motions are prevented." The constrainment of motion now becomes a fundamental condition for every mechanism, and subordinates the mere question of directional—relation or of velocity-ratio, as determined by the comparative motion of any two points of the mechanism. A machine is a mechanism so operated as to do work, and is stated by Reuleaux to be "a combination of resistant bodies so arranged that by their means the mechanical forces of nature can be compelled to do work, accompanied by certain definite motions."

The Electro-magnetic Connection of Moving Parts, in a mechanism or a machine, followed naturally upon the inclusion of hydraulic and pneumatic modes of communicating motion. For development in any line becomes apparent when a general identity is to be seen through many special varieties. And, however varied may be the mechanical movements of any machinery, or however simple the relative motions amidst the complicated mechanism, the ultimate analysis shows simple well-known motions, obtained by well-known pairs of elements and kinematic chains, whether such chains are composed entirely of rigid connecting elements, or of hydraulic, pneumatic, or electro-magnetic connection. Seeing, therefore, that the time was ripe for another mode of connection in mechanism, and which should

include the electro-magnetic forces of nature as among "the mechanical forces of nature [that] can be compelled to do work, accompanied by certain definite motions," Sylvanus P. Thompson has given us the term "Electro-magnetic Mechanisms," and considered them somewhat at length in connection with his work on *The Electro-magnet.* It is my purpose in these papers to speak of these mechanisms when put to do work, as electro-magnetic machines; and the general term, electro-magnetic machinery, will include such mechanisms as may be more or less useful in the conversion of motion under constrainment, and such machines as may be useful in the direct transmission of energy—by electro-magnetic means.

The Medium for the Transmission of Energy may likewise serve, as it often does, as the means for communicating motion; and, when energy is transmitted along with the conversion or transfer of motion in any mechanism, that mechanism becomes a machine. Any medium, therefore, which is of such a nature as to admit of its being made a part or link in the mechanism of the energy cycle, will serve in almost all cases, equally well for the transmission of energy or of motion; provided, that notwithstanding the deformations to which it may be subjected, the medium is capable of returning to its original condition. Some mediums or links are practically incompressible and inextensible, within the usual limits of the transmitted energy; such as, iron rods, retaining their form throughout; and a water connection, which retains its volume while altering its volume-form. Other mediums admit of practical extension, but are of little use in compression; such as, belts, wire ropes, and like flectional elements used as wrapping connectors in mechanism. Compressed air, springs, and like flectional elements admit of practical extension and compression, and are of more or less value in the transmission of energy; but, of little use as elements or links of a kinematic chain, for constrained motion. In all of these energy is transferred by and through matter in some one of its many forms—matter which follows the laws of the continuity of matter and of space, while entering as a medium in the continuity of energy.

Systems for the Transmission of Energy have therefore become quite definitely established, for long or short distances, and have taken the following broad lines of development:

(1) Mechanical transmission, by belts, wire ropes, and other wrapping connectors for long or short distances; and, by gear-wheels, links, screws, cams, ratchets, and like forms, for more immediate and direct transmission.

(2) Hydraulic transmission, with pumps, accumulators, connections, motors and presses, more or less varied in form for utilizing water-pressure.

(3) Pneumatic transmission, with the compressors and apparatus especially adapted to that medium.

(4) Electric transmission, with dynamos, line connections, regulators and motors, and chiefly used in long-distance transmission.

It is proposed to add:

(5) Electro-magnetic transmission,* in which the dynamo and motor, as generator and receiver, or as driver and follower, shall be in the same magnetic circuit; or, in which the magnetic circuit shall be used for direct and immediate distribution of energy for very short-distance transmission, in much the same way as the electric circuit is even now used for long-distance transmission.

The Ether as the Medium for the Transfer of Energy, by electric or electro-magnetic means, has been found to possess many striking analogies to other and better known mediums. By the modern theory of electricity, the electric energy is supposed to be concentrated in the ether surrounding the conductor, or other core of disturbance, and that a transfer of the ether energy takes place whenever electric energy is being transmitted from point to point. However great may be the contrast between the mechanical, hydraulic and pneumatic transmission of energy and the *etheric* transmission, it remains a fact that energy may be transmitted by all of these means, with varying degrees of

* Paper read before the Electric Club of the Johns Hopkins University, November 9, 1891, on "Notes on Electro-magnetic Transmission of Energy."

efficiency, and accompanied, if desired, by definite conversion of motion. The former three require some material connecting-link between driver and follower—some kind of contact of elements, or some pairing of surfaces—while the etheric transmission requires no such material contact or pairing; indeed, such contact may kinematically lock the whole mechanism, as an armature, in contact with its core in some special forms of this type of electro-magnetic mechanisms. The ether medium allows of the transmission of constant or varying forces, as now transmitted by more material modes of connection; and, with the peculiarities of comparative and constrained motion accompanying such energy transmission. By the displacement theory, electricity seems to act as an incompressible fluid. By the researches of Hertz, the ether appears to be possessed of some peculiar mechanical properties, such as inertia, and stress and strain manifestations. We have even come to conceive of the mechanism of the ether medium, and to picture some of the peculiar manifestations of the ether mechanism as analogous to gear-wheel mechanisms.

The Kinematic Conception of the Ether Mechanism, in combination with the peculiar mechanical properties apparently possessed by the ether medium—however far from being a true conception, may serve the passing moment till a better working hypothesis is presented. We know that the ether energy of the electric current and of the magnetic circuit, moves at right angles (normal) to the direction of the current or the axis of the magnet; also, while the instantaneous direction of motion of a point in the pitch circle of a gear-wheel is tangential to its path, the energy is transmitted radially or normal. These peculiar gear-wheel properties of the kinematics of the ether mechanism, like all good illustrations, leave us in doubt as to many points; especially, as to whether the ether gear-wheels are more or less flexibly mounted, as on springs, but with apparently limited or even fixed distances between centres. Perhaps Oliver J. Lodge may yet point out to us whether these gear-wheels, as elements in the ether kinematic chain of mechanism (speaking in the phraseology of Reuleaux) are pair-closed, force-

closed, or chain-closed. That is, whether they mesh with each other by reason of some peculiarity of their paired connection or characteristic conformation of their toothed outline; or, are by some force kept in geared connection, akin, perhaps, to the manifest tendency of the magnetic circuit to complete or perfect itself—to enclose the greatest possible number of lines of force in following the path of least resistance, and yet to remain as undeformed as possible in the presence of opposing magnetic forces—a kind of electro-magnetic force-closure; or, perhaps, these ether gear-wheels may have their centres connected by a link or chain device, not yet made clear. And the time may come when the kinematics of this hypothetical mechanism of the ether may be as definitely studied as its mechanics; and, the paths of its moving elements as clearly laid down as now in the case of link-work, cams, gearing, etc. The ether medium has already been made to yield some of its many possibilities in the applications of electricity and magnetism; and, its peculiar characteristics show it to be capable of the widest range of usefulness in the transmission of energy and of motion, for a long or short distance, and by immediate and direct, or by indirect means. And the beautiful electro-magnetic induction experiments of Elihu Thomson, the high frequency alternating-current effects obtained by Tesla, and the researches of Crookes in high vacua—give grounds for hoping that the day is near at hand when these invisible forces will be clearly seen and understood by the things that are made.

Electric Transmission of Energy is shown in simple ideal form in *Fig. 1* for long distances; in *Fig. 2* for short distances. In either case, but especially the latter, we may suppose the axes of the two armatures to be placed parallel, or in any given oblique position to each other, being then similar to transmission by belts and wire ropes. The speeds of the two shafts may be maintained constant under changes of load, or varied at will; and the rotations may be in the same or opposite directions, and, reversible at will. The current used may be direct or alternating. Power applied to drive one as a dynamo, will drive the other as a motor;

while if power be applied to both, the output will be current in the external circuit, as given by two dynamos coupled for any given output. Current supplied to drive one as a motor will serve to drive the other as a dynamo, giving an electric-motor-driven dynamo as a transformer, if

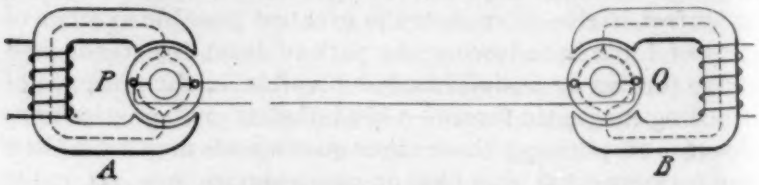


FIG. 1.—Long-distance electric transmission of energy.

the two shafts are in any way coupled or geared; while, if current be supplied to both, the output is power from each machine acting as a motor. More than two machines are often used, and sometimes one dynamo operates several motors in the same electric circuit, but with individual

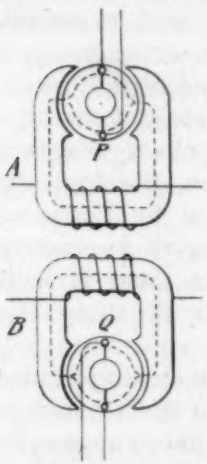


FIG. 2.

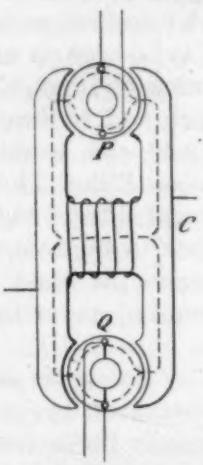


FIG. 3.

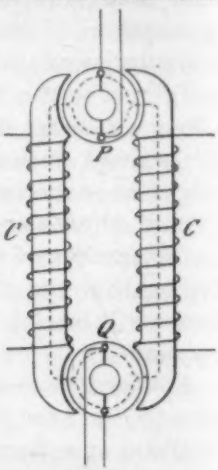


FIG. 4.

Short-distance electric and electro-magnetic transmission of energy.

magnetic circuits. In the figures from *1* to *12*, inclusive, *P*, *Q*, *R*, represent armatures and armatured shafts, and *A*, *B*, *C*, fields and field coils.

Electro-magnetic Transmission of Energy is understood to mean that combination for the transmission of energy in which all the armatures are in the same magnetic circuit.

(*a*) One or more of these armatures, as dynamos, may be utilized to generate current, which may be supplied to the remaining armatures, as motors, in the same magnetic circuit; or, (*b*) all the armatures may be run as motors by an external source of supply of current; or, (*c*) all the armatures may be run as dynamos by an external source of

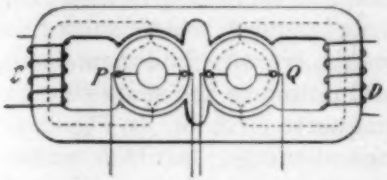


FIG. 5.

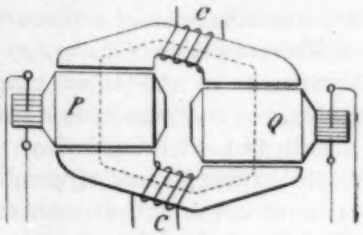


FIG. 6.

Dynamotors for parallel shafts in close proximity.

power. *Figs. 3, 4, 5, 6, 7* and *8* show such combinations of two armatures in the same magnetic circuit, or branches of the same. (*a*) If armature *P* is driven by power, as a dynamo, the current supplied to armature *Q* will drive it as a motor; or, (*b*) if current is supplied to both armatures *P* and *Q*, they will run as motors; or, (*c*) if power is applied to both armatures, current will be generated in the exter-

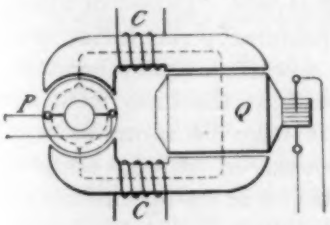


FIG. 7.

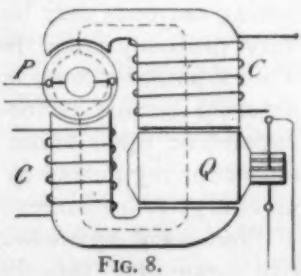


FIG. 8.

Dynamotors for intersecting and non-intersecting axes.

nal circuit. This last combination is similar to a separate-circuit self-exciting dynamo (type of *Fig. 4*), brought out by Ladd, March 14, 1867, which had two shuttle-wound armatures—a small one to excite the common field magnet, and a large one to supply currents for electric lighting. We may also arrange any one of the forms shown (*Fig. 2*, for

instance), as a dynamo-transformer, by supplying current to armature *P*, acting then as a motor, and gearing or otherwise coupling the shafts *P* and *Q*, so that armature *Q* acts as a dynamo, giving a transformed current within any given range.

Dynamotors for Electro-magnetic Transmission of Energy are combinations of armatures in the same magnetic circuit, as illustrated in *Figs. 3, 4, 5, 6, 7* and *8*, which show two armatures in the same magnetic circuit, as dynamo and motor. A dynamo-motor combination, in the same electric circuit, but with *individual* magnetic circuits, as *Fig. 2*, is really a transformer of mechanical energy; while a motor-dynamo combination, similarly arranged, is a transformer of electrical energy. The dynamotor is also a dynamo-motor combination, in the same electric and the *same* magnetic circuits, *Figs. 3, 4, 5, 6, 7* and *8*, and as such is also a transformer of mechanical energy; but it may also be used as a transformer of electrical energy. These dynamotors allow of a constant or variable velocity-ratio being electro-magnetically transmitted between two shafts arranged in any way with inclose proximity, for the immediate and direct transmission of energy. The direction of rotation as well as the velocity-ratio may be varied at will. Direct or alternating currents may be used, but preferably the latter, and very probably some form of the so-called rotary current. The dynamotor may be an independent machine, with no external circuit connections, or it may be more or less dependent upon some external source of current supply, either for regulation of velocity-ratio, or of its operations as an energy transformer.

Mechanical Equivalents of Dynamotors are those mechanical means for the transmission of energy and motion, equivalent, from the standpoint of kinematics, to the electro-magnetic means employed in the dynamotor. Thus *Figs. 3* and *4*, show dynamotors for parallel shafts, in ordinary proximity, and have their mechanical equivalents in belts, spur gearing and like means for the transfer of circular motion between parallel shafts. *Figs. 5* and *6* show dynamotor forms for parallel shafts very close together, as

in Oldham's coupling. Shafts intersecting at an angle, such as in bevel gearing, universal joints, Hooke's joint, etc., are mechanically equivalent to the form of *Fig. 7*. Screw wheels, worm wheels, and skew-bevel wheels, are mechanically equivalent to the form of *Fig. 8*, for transmission between non-intersecting axes.

Magnetic Circuits in Parallel and in Series admit of a variety of ways of grouping two or more armatures in electromagnetic machinery. *Fig. 9* shows the simple ideal grouping in parallel or magnetic shunt, with one energizing coil. The ends of the field, at armature *R* may be closed around, and another coil put in, acting in conjunction with the coil *C*. And with or without this additional coil, separate auxiliary energizing coils, acting in the way of feeders, may be placed between armatures *P* and *Q*, and *Q* and *R*. The

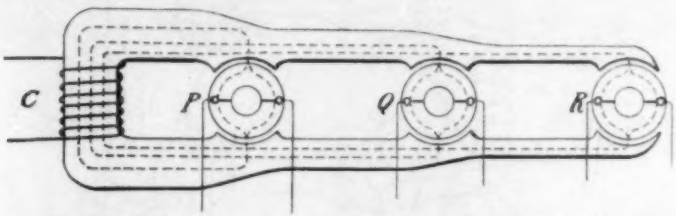


FIG. 9.—Simple ideal grouping of armatures in magnetic shunt, or parallel.

simple magnetic shunts, to which Sylvanus P. Thompson refers* may develop into useful industrial applications, such as multiple drills, operated by spindles on armatures arranged in parallel magnetic circuit. Other forms of branch magnetic circuits are shown in *Figs. 3* and *5*. The simple ideal grouping of armatures in series in the magnetic circuit is shown in *Fig. 10*, with one energizing coil. As before, auxiliary energizing coils may be placed at the other end, or between the armatures *P* and *Q*, and *R* and *S*, but these coils do not here act as feeders as they did before in the parallel arrangement, but rather as separated parts of one large coil controlling the one magnetic circuit. This

* "On a Property of Magnetic Shunts," communicated to the Physical Society, April 17, 1891. See *The Electrician* (London). Vol. xxvi. April 24, 1891, p. 764.

may be clearly seen by referring to the field coils in *Figs. 4, 6, 7* and *8*, which show the arrangement of two coils in series for one magnetic circuit.

The Electro-magnetic Kinematic Chain may be developed by reference to *Figs. 11* and *12*. Multipolar types are preferably here used. If the arm *L*, connecting the two fields in *Fig. 11*, be *fixed*, the combination may be used as a dynamotor. And by driving armature *Q* as a dynamo, by power, or by a motor secured to the arm *L*, armature *P* will operate as a motor, turning at a certain definite and predetermined speed with respect to *Q*. Should the armature *P* be slowed down by a *fixed* brake or clutching device, and the armature *Q* rotated as before, there will be a rotation given to the field

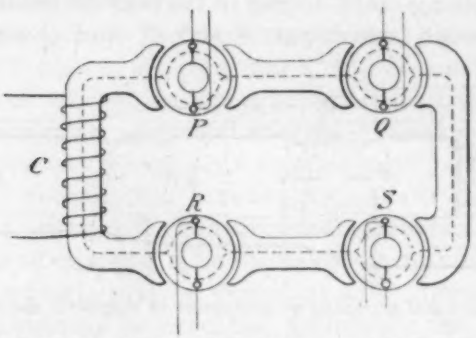


FIG. 10.—Simple ideal grouping of armatures in series, in the magnetic circuit.

C_1 of *P*, in the *opposite* direction to which the armature *P* is turning, in order that the lines of force across *P* may continue to be cut at the same rate as before; that is, when the field was fixed and the armature was free to revolve. If armature *P* be wholly stopped, its field C_1 will turn around, carrying the arm *L* and its appurtenances, at the same speed at which the armature was formerly turning, but in the opposite direction. If, on the other hand, the speed of the armature *P* be increased, by applying external power, then, to cut the lines of force at the designed rate, the field C_1 of *P*, and so the arm *L*, will have to turn around in the *same* direction as the armature *P*. The armature and its field form an electro-magnetic turning pair of elements; in

the first case above, acting as a motor-turning pair, and in the second case as a dynamo-turning pair of electro-magnetic elements. The placing of two armatures, P and Q, in the same magnetic circuit makes it an electro-magnetic connecting link between them; while, if placed simply in the same electric circuit, they form a combination of elements electrically linked. The electro-magnetic chain is then built up of electro-magnetic links, which connect electro-magnetic pairs of elements. Two or more armatures may therefore be electro-magnetically arranged in series or parallel, or any of the usual modifications and combinations of these groupings. And, from the kinematic standpoint, two or more armatures, with their fields, may be kinematically arranged as an electro-magnetic kinematic chain; the mechanical

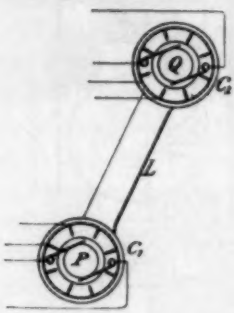


FIG. 11.

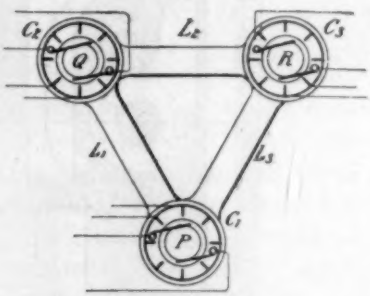


FIG. 12.

Elements of an electro-magnetic kinematic chain.

equivalents of this combination may be seen in belt kinematic chains, wheel-kinematic chains, and crank (linkage) kinematic chains. In general, then, an electro-magnetic kinematic chain may be considered as a combination of electro-magnetic connecting links, so connecting pairs of electro-magnetic elements, that all parts of the chain have determinate motions; such motions being determined by the form of the elements carried by the links, and independent of the application of external force when considered merely as a change in position. *Fig. 12* shows a simple ideal electro-magnetic chain of three links. Whether the armature P is held fixed, or is rotated, certain definite motions may be obtained from the armatures Q and R, in either case. Fix-

ing the centres of armatures Q and R (the same as fixing the rigid connecting link between P and Q, of *Fig. 11*) would lock this three-link chain, so far as any motion of the centre of P, in space, would be concerned, and the armature P would then revolve as about a fixed centre. Kinematic chains of four or more electro-magnetic links admit of a greater variety of relative and constrained motions; and, as in any case, become convertible into a mechan-

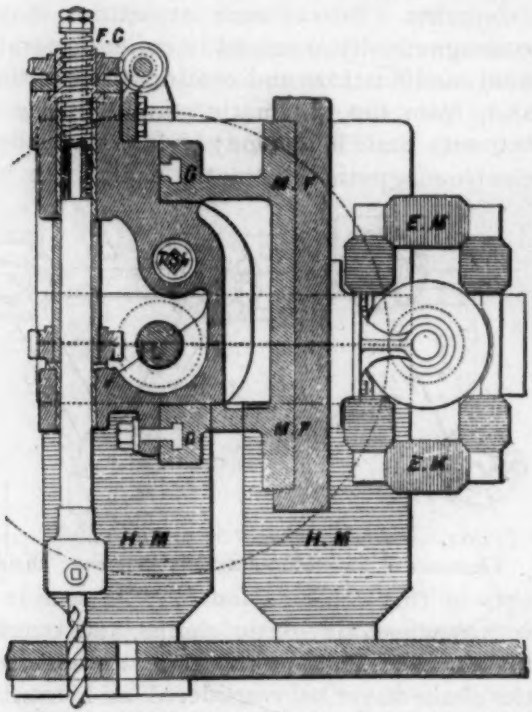


FIG. 13.—The Rowan electric drill with electro-magnetic clamp.

ism by fixing one link. The extreme flexibility of the electro-magnetic connection admits of many combinations of the simple electro-magnetic pairs for producing rotation, translation or helical motion.

Some Industrial Applications of Electro-magnetic Machinery have been taken from among the many drills operated directly or indirectly by these means. Drilling operations admit of peculiarly compact and portable machines, and

ready adaptation of either rotary or reciprocating motions produced and controlled by electro-magnetic means.

The Rowan Electric Drilling Machine, with an electro-magnetic clamping device, is shown in *Fig. 13*.* The main frame, *M F*, is easily placed in position, and electro-magnetically clamped by the holding-down magnets *H M*, to the iron or steel plates to be drilled. The drill is then operated through the usual mechanism for increasing or decreasing the speed, from an electric motor, *E M*, mounted on the main frame *M F*. The feed is by hand, through the feed-gear *F G*. The drill can be moved over the work, along the guides, *G*, *G*, by the transverse shaft, *T Sh*. The Willet's portable electric drill cuts holes two and three-eighths inches diameter through two and one-half inch steel armor-plates, in position on deck, in twenty-one minutes. This work formerly required two men, working a half-day each.

The Van Depoele Reciprocating Electro-magnetic Mining Drill is a good example of the direct application of a controlled reciprocating movement. The length of stroke is about five and one-half inches, and at every stroke the drill turns automatically one-eighth of a revolution about its axis, so that the drilled hole is truly cylindrical. The forward advance is made by a feeding screw operated by hand. About two horse-power is absorbed in drilling holes from one and one-half inch to two inches diameter. In experiments at Frankfort, 1·4 inches diameter holes were drilled per minute, in gypsum blocks, to a depth of 7·9 inches with water, and 4·7 inches without water. In Odenwald granite, a hole 1·7 inches diameter and fifteen and three-fourths inches deep was drilled in ten minutes.† Two thick-wire outer coils, *1* and *3*, with a thin-wire inner coil, *2*, are wound, side by side, and secured to an iron casing, completely closing in the magnetic circuit, and so forming an efficient iron-clad construction. The drill-spindle is attached to an iron core introduced into the coils. The coils

* *Electrical World*, 1887, June 25, p. 301.

† *The Electrician*. London. Vol. xxviii, Nov. 6, 1891, p. 10.

1 and *3* are oppositely wound, so that they are equally and oppositely polarized, and connected up in series with the *rotating* brushes, R and R_2, of the generating dynamo, or of the distributing motor-dynamo; these coils are therefore traversed by an alternating current. The coil *2* is connected, at one end to the *fixed* brush F_2, and at the other end to the junction of coil *3* with the rotating brush R_1; it is therefore traversed by a pulsating current, and exerts the chief magnetizing effect upon the reciprocating iron core, with a constant polarity. Speaking kinematically of this combination of electro-magnetic elements, forming an electro-magnetic kinematic chain composed of reciprocating pairs, it is seen that the motion of the iron core is determined to a definite extent by the constant direction

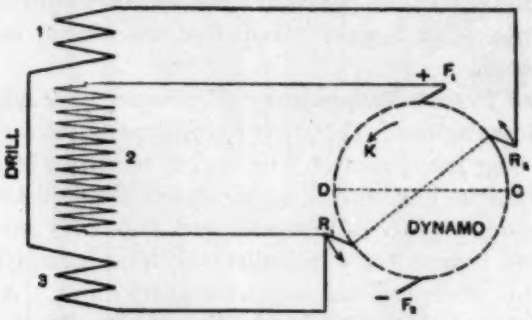


FIG. 14.—The Van Depoele reciprocating electro magnetic drill.

(polarity) and variable energizing coil *2*, in combination with the variable direction (alternating polarity) and variable energizing coils *1* and *3*. Moreover, the iron core, as an electro-magnetic link, under the influences of its electro-magnetic pairing with the energizing coils, has its motion completely constrained. This electro-magnetic constrainment of motion of the iron core link of the chain, constitutes the combination a true electro-magnetic mechanism; and when the electro-magnetic forces of nature can be compelled to do work through and by this electro-magnetic mechanism, we have a pure electro-magnetic machine. It is to be especially noted that the enveloping forms of the pairs of electro-magnetic elements, are such that there is no contact of these elements, while in mechanically-connected pairs

of elements the contact of the enveloping forms is a necessary condition to the constrainment of motion. It is therefore possible, in a pure electro-magnetic mechanism, to have constrained motion without the contact of material elements. Oftentimes practical considerations preclude the possibility of using electro-magnetically constrained motion; and, it is found best to constrain the motion mechanically by the pairing of material elements; such as, the cylindrical turning pair of elements in the dynamo or motor, and the cylindrical sliding pair of elements guiding the drill-spindle in the Van Depoele reciprocating drill.

Direct and Indirect Electro-magnetic Machines are those in which the transmission of energy, through an electro-magnetic mechanism, is of a direct or of an indirect character, according to whether the electro-magnetic forces act directly at the point of application (as in the Van Depoele mechanism), or indirectly through the intervention of other mechanism, such as a train of wheel-work, as in the Rowan machine. The indirect transmission is, in fact, through electro-magnetically *actuated* mechanisms or devices, which are of themselves essentially of another system; or which call into operation other forces of nature than the electro-magnetic forces; such as the wheel-train of the Rowan machine, transmitting the energy by purely mechanical means, from the electro-magnetic mechanism of the electric motor to the drill-spindle. It is to be remarked that the self-fixing or clamping device of the Rowan machine, acting as it does by the application of electro-magnetic traction, is an example of a locked kinematic chain, and that in this particular case such a locking, clutching or clamping action is brought about by the contact of material elements in the magnetic circuit. There are, however, examples of such a locking action with no contact of the material elements of the magnetic circuit, as may be seen in the Faraday copper-disk type of dynamo, used as a true electro-magnetic clutch or brake.

The diagram of the cycle of operations of the electro-magnetic mechanism of the Van Depoele machine, will be presented in the next paper.

CORRESPONDENCE.

To the Committee on Publications:

DEAR SIR:—I have read with great interest Mr. John Birkinbine's article upon the "Pig Iron Manufacture of the United States," in which reference is made to some of my own computations. May I venture to call Mr. Birkinbine's attention, as well as that of your readers, to the fact that in my somewhat visionary indication of the centre of the future situs of the iron industry of this country, within a circle of about 150 miles diameter, centring on the Great Smoky Mountain in North Carolina, I did not intend even to suggest that *the whole manufacture of pig iron would be concentrated within that circle*. Of course, such a suggestion as that would be absurd.

What I did intend was this: that if the development of ore within that section should be as great as the indications appeared to show that it would be, that section might become the main source of the pig iron supply. But this would not be inconsistent with the production of pig iron at many other suitable points in lesser measure, although that section might become the source of the larger part.

Were I to state the case again, in view of the more recent developments of Bessemer ores, I might perhaps take Cumberland Peak rather than the Great Smoky Mountain from which to extend a radius of seventy-five to 100 miles. But of course all such forecasts must be more or less visionary. If, for instance, the inventions for the electric concentration of ores should be as successful as their promoters hope, the low grade ores of the other sections, where they exist in excessive abundance, may be converted by concentration into Bessemer ores, thus putting a new aspect upon the case.

Again, if some of the undertakings which are apparently very promising in the line of direct processes and other methods of treating ore and fuel should prove a success, the so-called impurities in ore and coal may cease to be of consequence, and then the centre of production might fix itself at the point at which the greatest abundance of ore, coal and limestone can be assembled with the least labor and with the least length of haul. Have we yet begun to deal with heat in any but crude and wasteful methods?

It would, of course, be an impertinence for one like myself, who has no scientific knowledge of the iron production, and who merely deals with the figures and facts as they are presented at a given date, to do anything more than to call attention to the accelerated demand for iron and steel, and to the law which pervades this branch of industry as well as every other, to-wit, that in proportion to the application of science and invention under conditions that are free from obstruction by taxation or otherwise, the abundance of this and every other material is assured at a lessening cost to the consumer, with higher rates of wages or earnings to the workman, and better conditions of life for all. In this particular instance the obstruction to the import of foreign ores has, to some extent, prevented the natural working of this beneficent law. But this is an incident, probably a very

temporary one; suffice it that either at the centre indicated by myself or at some other point not very far from there, the future centre of the crude iron production of this country and of the world will probably be established.

Yours very truly, EDWARD ATKINSON.

Boston, December 31, 1891.

BOOK NOTICES.

The Practical Catechism.—A Collection of Questions on Technical Subjects, by Manufacturers and Others, and of answers thereto. By Robert Grimshaw, M.E., Ph.D. New York: John Wiley & Sons, 53 East Tenth Street. 1891.

We have here the kind of book which the poet must have had in mind when he wrote: "I mean to show things as they really are, not as they ought to be, for I avow that till we see what's what in fact, we're far from much improvement." The reviewer would have rejoiced in the possession of this book in early days when, as it seemed, he wanted to know about many things, while not a pointer could be found to tell the way to any one of them. Knowledge like hidden treasure may have existed, but there was no known way to it. If facts lie at the foundation of science, here's abundant material squared and smoothed ready for the building.

Of course, a pocket manual in diminutive, as this, can't hold everything, but any work well begun is half done, and this book gives earnest proof of the truth of this adage.

Guide books, misjudging common requirement, frequently tell what you don't want to know; but such criticism fails here, for there's not a page that does not show up well of solid grains with least chaff—grains of truth ready for the miller, and no smut machine needed. What a refreshing treat it is to get facts and data already purified of dross and well nigh adapted to immediate use! Engineering life is too short to wade through long chapters to find the meaning of a letter, or the simplest form of a usable formula, and at the end conclude perhaps, that the author has been "barking up the wrong tree," for the game the reader is after. There's no uncertain sound here, and you don't get off the scent either.

Taking a glance at the index with its forty-two pages, each having fifty or more references, the reader concludes that the author has pretty numerously covered a great variety of subjects. Beginning at absorption, which is prophetic, the reader is conducted through acids, air, alloys, dwelling in a museum of aluminium by the angle of repose, through anti-friction curves to apples and applewood, which makes the best of guides, to a checquered array of areas, thence to the atmosphere; but it is this way, in endless variety, all the way down the alphabet. The reviewer must stop, however, at belts, as one wishes to see how things look about home. This subject reminds him of an early hunt for belt data, where the published rules gave

results all the way from *one* to *five*, a divergence altogether inadmissible in the realm of machine economy.

Our author of wide and later research finds a happy medium between utter *insufficiency* and enormous *excess*, giving for use the figures fifty to sixty-six pounds per inch of width, at any velocity, as a fair carrying capacity of single belts, while we may add that, if forty to sixty-six pounds be taken, these figures will embrace those concluded upon by many good modern authorities, who stand squarely upon successful practice.

It seems idle to dwell upon so small a matter, but it takes a great deal of time and a wide experience often to arrive at a simple general statement or rule, which will compass the needs of usual practice; in this book we have much of this kind of data in a very get-at-able shape.

The many sources from which this matter has been obtained, must give it value, and the occasions and opportunities for securing it being rare and fruitful, must add to and greatly reinforce that value. Out of the great mass of material, a judicious selection has been made, such as would benefit the largest number of practical men; to this class of readers the author commends his work, and the reviewer seconds his invitation to the feast of facts, which he has prepared and set forth in this little volume. J. H C.

The Metallurgy of Silver, Gold and Mercury in the United States. By Thomas Egleston, LL.D., etc. Vol. II. Gold and Mercury. New York: John Wiley & Sons. 1890.

The review of the second volume has been so long delayed (through no fault of the Franklin Institute) that much which would otherwise have been said is rendered unnecessary, inasmuch as other reviews have said it. This volume is a great improvement over the first, both on account of what it contains and of what it omits. Its eight chapters, covering 901 pages, contain much interesting and important matter. The historical part of the subject, while not always free from error, is well treated, and shows evidence of careful research.

The illustrations and descriptions of the various kinds of mining, with the statistics of cost, will make this book always necessary as a book of reference. The pages devoted to the measurement, management and cost of water are full of important matter, as are those on "débris litigation." The processes of drill mining and the description of the preparation works follow those of flumes, ditches and sluices.

After the mills comes the metallurgical operation of roasting. The leaching and quartation, the melting and minting, occupy seven of the eight chapters, and 798 of the 900 pages. The last chapter is devoted to mercury, its ores, its treatment and production, and its cost.

Altogether it may be said to be the most complete compendium of the prospecting, mining, producing and assaying of gold and mercury which can be found in the language. A very full index makes the work still more valuable. It will be a necessity in the library of all who are interested in the subjects treated, and who can afford to buy it. F.

The Phosphates of America. When and How they Occur; How they are Mined and what they Cost, with Practical Treatises on the Manufacture of Sulphuric Acid, etc. By Francis Wyatt. Second edition. New York: The Scientific Publishing Company.

This is a valuable book of 178 pages, royal 8vo, which gives besides a general introduction on the agricultural side of phosphates, a history of the apatite mines of Canada, belonging to the Archean division of the geological scale, and the bone or rock phosphates of the Cenozoic age in South Carolina and Florida. The manner of occurrence, relation to the surrounding rocks, methods of exploitation and of mining, the laws relating to the subject and the statistics of production are all given with the succinctness and method of one who is a master of this subject and who is familiar with the presentation of philosophical papers. It is illustrated richly by photo-engravings which add very much to the clearness of the work.

Chapter VIII is consecrated to the best methods of phosphate, limestone, pyrites, etc., analysis, and this is thoroughly taken up.

The last eleven pages of the work are concerned with directions for the preparation of the necessary laboratory reagents, useful tables for computation, etc.

It covers a field entirely its own and covers it so well that it must be accessible to any one who is interested in phosphates; indeed, even if the book were only half as reliable as it is, the chemist, geologist, manufacturer and shipping merchant would need it for reference. F.

The Washington Bridge over the Harlem River at One-hundred-and-eighty-first Street, New York. A description of its construction. By William R. Hutton, Chief Engineer. New York: Leo von Rosenberg. Price, $8.

The monograph above cited is similar in style to other publications, descriptive of special engineering works, issued by the same publisher. It forms in itself an exhaustive description of the important structure of which it treats, and will prove a most valuable work for the bridge designer and constructor, for whom it is specially intended.

As will be inferred from the foregoing remarks, the feature of the work which gives it its peculiar value to the specialist resides in the illustrations, which comprise general views and plans, views of the work in different stages of completion, views of the completed structure, of the iron work, of the details of the masonry and superstructure, etc. These illustrations give a complete description of the bridge from the engineering standpoint.

The text covers a descriptive account of the construction, and copies of the contract and specifications, which, with the wealth of illustrations, constitute one of the most complete and satisfactory monographs that it has been our pleasure to notice in these columns.

We cannot refrain from special commendation of the illustrations, which are executed in admirable style, and of the mechanical excellence of the work as a whole, which reflects credit on the publisher. The engineering profession in America will, no doubt, duly appreciate these facts. W.

ANNUAL REPORT OF THE BOARD OF MANAGERS OF THE FRANKLIN INSTITUTE.

(For 1891.)

The Board of Managers of the Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, respectfully presents the following report of the operations of the Institute for the year 1891:

MEMBERS.

Members at the close of 1890,		2,169
Number of new members elected who have paid their dues,		112
		2,281
Lost by death or resignation,	99	
Dropped for non-payment of dues,	109	
		208
Total membership at close of 1890,		2,073

FINANCIAL STATEMENT.

Balance on hand January 1, 1891,		$657 71
Receipts:		
Contributions from members, annual,	$5,771 00	
Contributions from members, life,	580 00	
Certificates of stock, second class,	60 00	
Income from legacy of Geo. S. Pepper,	1,034 30	
Income from estate of John Turner,	13 25	
Income from Bloomfield Moore fund,	750 00	
Income from memorial library fund,	57 17	
Interest on investments new building fund,	340 00	
Interest on B. H. Bartol fund,	60 00	
New building fund subscriptions,	150 00	
Interest on investment of Institute funds,	794 00	
Temporary loan,	3,200 00	
Cash from subscriptions to, and sales of, the *Journal*, fees for drawing school and other sources,	10,248 66	
		23,058 38
		$23,716 09

Payments:

Committee on library,	$1,703 03	
Committee on instruction,	2,573 12	
Curators,	2,238 20	
Salaries and wages,	4,420 91	
Insurances,	900 00	
Bloomfield Moore fund expenditures,	683 78	
Memorial library fund expenditures,	31 69	
Investment memorial library fund,	105 20	
Board of Trustees, subscription to new building fund,	150 00	
Temporary loan,	2,200 00	
Interest on temporary loan,	85 84	
Other expenditures,	8,274 65	
		$23,366 42
Balance on hand, December 31, 1891,		$349 67

LIBRARY.

The additions made to the Institute's collection of books and miscellaneous publications during the past year have been somewhat greater than the average of late years, exhibiting an increase of about thirty per cent. over the figures of the previous year.

The details of the operations of the library appear in the committee's annual report to which the board refers.

No change has been found necessary or desirable in the rules regulating the use of the library by the public, which shows a steady increase, and but one case of the abuse of the non-members' privilege has been reported by the committee.

The Committee on the Library has strongly urged upon the board the necessity of taking measures looking to the more adequate protection of the building against destruction by fire, and at the present time, several suggested plans for accomplishing this object are under consideration. In connection with this important subject, the board desires to call attention to the fact that the very limited financial resources of the Institute interpose a serious obstacle to carrying any suitable plan into effect.

THE JOURNAL.

The annual report of the Chairman of the Committee on Publications, exhibits the fact that the *Journal* has continued to be self-supporting during the past year. The board desires, however, to emphasize the fact that this condition of things is due in much larger measure to good management than to the generous patronage of the members of the Institute.

In evidence of this it will suffice to state the fact that of the total income of the *Journal*, from subscriptions, advertisements, sales of copies, etc., less than ten per cent. is derived from the membership of the Institute.

While expressing its satisfaction with the present direction of the affairs of the *Journal*, the board renews its recommendation to members to support it more liberally.

It is the only record in which the educational and scientific work of the Institute is preserved, and the only means by which its activity is made known to the world, and has contributed more powerfully than all the other agencies at our command to establish and sustain the high reputation which the Institute enjoys. The Committee on Publications at present is carefully considering certain plans for extending the influence and usefulness of the *Journal*, which, when matured, it is hoped, will meet the cordial approbation of the members.

COMMITTEE ON SCIENCE AND THE ARTS.

The record of the work of the Committee on Science and the Arts during the past year is highly creditable.

The number of cases upon which reports were made is about the same as in the previous year, and of these, several were of unusual importance, and entailed great labor in their investigation. The committee is about to enter upon the sixth year of its existence as an elected body, and the greatly increased efficiency of its work affords conclusive evidence of the wisdom of the change effected in its organization.

The board refers to the annual report of the Chairman of the Committee for the details of its work.

LECTURES.

The Committee on Instruction has found no cause to depart from its policy pursued for the past five or six years, of inviting men of note to lecture before the Institute, and thanks to the zealous co-operation of the professors, the committee has been enabled to offer the members a series of lectures of excellent character.

The lectures delivered under the committee's auspices during the year 1891, numbered thirty-one, of which seventeen were of such scientific importance or technical interest as to warrant their publication in the *Journal*.

THE DRAWING SCHOOL.

The number of pupils in the Drawing School, in 1891, exceeded that of any previous year, and the board is gratified to be able to assure the Institute of the continual efficiency.

The figures of attendance are as follows:

At the spring term of 1891, ...	247
At the winter term of 1891, ...	258
Total, ...	505

An increase of thirty-two over that of the previous year.

SECTIONS.

The past year exhibited a gratifying growth of interest in this branch of the Institute work.

An inspection of the annual reports of the Chemical and Electrical Sections, appended hereto, will show considerable additions to the membership and an increase in the amount of work accomplished. The papersr ead at the section meetings afford very desirable material for the *Journal*, and add greatly to its interest, but the greatest benefit of the sections is to be found in the stimulus they give to the work of original research, which cannot be overestimated.

STATE WEATHER SERVICE.

The failure of the State to continue the appropriation for the expenses of the State Weather Service compelled the Committee on Meteorology to abandon the publication of the monthly reports. The committee has been enabled, however, with the assistance of the United States Weather Service, to maintain the organization of its work in the several counties of the State, and to continue, as heretofore, the collection of meteorological data, which are duly preserved, and which it hopes in time to be able to put in print. It is the committee's hope that at the next session of the Legislature, the appropriation for the continuance of this important work will be granted.

GENERAL REMARKS.

It is greatly to be regretted that the amount of receipts for membership is less than that of the previous year, and that the flattering exhibit of the year 1889 has not been maintained. The active work which was accomplished during 1889 by the Committee on Membership, seems to have languished, and to this must be attributed almost entirely the falling off in the accession to membership.

As a consequence, the financial exhibit for the coming year is not an encouraging one. With a city of over 1,000,000 inhabitants, and preeminently a manufacturing city, there is no practical reason why an institution organized as the Franklin Institute is for the promotion of the mechanic arts, established for nearly seventy years, and doing the effective work that is here done, should not have at least 5,000 members.

There is no sounder method of promoting the efficiency of such a school than this, and every cent added to its income adds so much more to the actual wealth of the city through its manufacturing interests.

Will not those who are members and those who are not, give this subject their serious consideration, and act for the good of the Institute and for the manufacturing interests of the city, the former by obtaining new members, and the latter by becoming members themselves?

Attention has already been called to the very limited resources of the Institute, interposing a serious obstacle to the adoption of any plan for the proper protection of the building, and its valuable library from fire.

This poverty of resources is felt in all the operations of the Institute, seriously restricting the extent of its work and depriving the membership and the community of advantages that would be of incalculable value to mechanics and artisans. With a new building and fire-proof library, with laboratories properly equipped, the Institute could use its great latent force

as a centre of unrivalled influence in the field of mechanic arts. It only needs an impetus on the part of some of our large-hearted citizens to accomplish this purpose so long cherished and heretofore fruitlessly attempted.

By order of the Board,

[SIGNED] JOS. M. WILSON,
President.

HALL OF THE INSTITUTE,
PHILADELPHIA, January 13, 1892.

ANNUAL REPORT OF THE COMMITTEE ON THE LIBRARY.
(For 1891.)

PHILADELPHIA, January 12, 1892.

To the President and Members of the Institute:

The Committee on Library respectfully reports the following summary statement of the operations of the library during the past year.

During the year the following additions were made:

Bound volumes,	1,508	
Unbound volumes,	660	
Pamphlets,	2,211	
Miscellaneous publications,	183	
Total additions,		4,562
Being an increase over the previous year of		1,263
The total number of volumes in the library at the close of 1890 was	35,015	
The additions of 1891 numbered	2,168	
Making the number of volumes at the end of the year 1891,		37,183
The total number of pamphlets in the library at the close of 1890 was	20,982	
The additions in 1891 numbered	2,211	
Making the number of pamphlets at the close of 1891,		22,183
The miscellaneous publications, such as maps and charts, designs and drawings, photographs, lithographs, manuscripts, etc., at the close of 1891 number		3,912

In addition to the above, the library possesses, in duplicates, as follows:

Bound and unbound volumes,	1,515
Pamphlets,	3,667
Periodicals (numbers),	2,119

The number of periodicals and publications of societies received by the library in exchange for the *Journal* of the Institute, at the close of the year 1891 was 380.

Among the noteworthy additions made during the past year, there should be named the patent reports of Switzerland, a complete set of which was presented to the Institute by the Swiss Government, also a number of important chemical journals, contributed by the Chemical Section; while the increased income received from the Bloomfield H. Moore Fund has enabled the committee to increase considerably the number and value of its purchases from this endowment.

The committee finds that the regulations relating to the use of the library for reference by non-members, which were put in force in 1887, though imposing considerable extra labor upon the librarian and his assistants, afford a satisfactory solution of what, previous to that time, had been a troublesome problem. During the past year, only a single case was reported in which the privileges were abused. The value placed by the public upon the privileges granted, is shown by the fact that during the year, nearly 1,000 non-members visited the library, consulting over 4,250 books and periodicals, of which more than three-fourths were patent reports, and the remainder, volumes and pamphlets on miscellaneous subjects.

The committee regrets that the chronic difficulty of lack of space is felt with increasing severity, as time passes.

At the committee's urgent solicitation, the board has made provision for the better protection of the library from destruction by fire, by authorizing the covering of a number of exposed windows with fire-proof shutters, which will soon be put in place. Respectfully submitted,

[SIGNED] W. P. TATHAM,
Chairman of Committee on the Library.

ANNUAL REPORT OF THE COMMITTEE ON SCIENCE AND THE ARTS.

(For 1891.)

HALL OF THE INSTITUTE,
PHILADELPHIA, January 4, 1892.

To the President and Members of the Franklin Institute:

The chairman of the Committee on Science and the Arts respectfully submits the following report of the operation of the committee for the year ending December, 1891:

At the opening of this year, there were forty applications for examination under consideration and awaiting action.

The number of new applications received during the year is	53
Of these there were accepted for examination and report,	46
There were declined,	5
And withdrawn,	3
The number of reports considered was	54

Adopted finally,	41
Advisory reports adopted,	3
Applications dismissed for insufficient information,	9
Applications under consideration by sub-committee at end of year,	40
Reports pending action of committee,	8

The recommendations of award of medals during the year were:

Of Elliott Cresson Medals,	3
Of the John Scott Legacy medals and premiums,	17

Medals granted and delivered during the year:

Elliott Cresson Medals,	3
John Scott Legacy Medals and Premiums,	15
Edward Longstreth Medals,	5
Certificates of Merit,	2

Medals awarded and held pending advertisement:

Elliott Cresson,	2
John Scott Legacy,	4

One protest against an award made by the committee has been received, which upon investigation did not appear to be sustained by evidence and was dismissed.

Several of the examinations made by the sub-committee during the past year embraced subjects of unusual interest and importance in the arts and involved in several cases a great deal of painstaking and exhaustive research, and more than usual expenditures in conducting them.

During this year a regulation has been operative requiring with each accepted application for examination the deposit of $5 with the actuary to defray the cost of necessary printing and illustration and searches into the state of art as shown in patent records, which regulation has been cheerfully acquiesced in by the applicants, and has been found to facilitate the work of the sub-committee by avoiding the delays incident to procuring such assistance through a correspondence between sub-committees and applicants through the secretary.

The classification and indexing of reports has been continued to date, and the addition to the indices to reports will appear in the *Journal* in due course.

During the year the committee has completed the arrangements for tests of hot-water heaters, in prescribing appliances to be used and regulations to govern such tests, in compliance with the request of the publishers of the *Metal Worker*, and the making of such tests by the advanced students of the engineering classes of the University, under the supervision of a sub-committee, has been arranged by Prof. H. W. Spangler in a most satisfactory manner.

The receipts during the year from all sources were	$609 21
Expenditures,	600 14
Showing a balance in the committee's favor, of	$9 07

The work of the committee has been a source of income from the profit of sales of extra editions of the *Journal* containing reports of the committee, which profits reappear in the receipts of the Committee on Publications.

The record of this year is, upon the whole, a satisfactory showing that the committee has fully worked up to the facilities afforded, and the character of inventions submitted for examination and the increasing demand for publications containing their reports clearly indicate public appreciation and approval.

S. LLOYD WIEGAND,
[SIGNED] *Chairman.*

REPORT OF THE CHEMICAL SECTION.

(For 1891.)

Mr. Joseph M. Wilson, President Franklin Institute.

SIR:—I have the honor to submit the following report of the proceedings of the Chemical Section, for the year 1891:

A consideration of the present condition of the section, and also of its history during the past year, shows that it has made very satisfactory progress for that interval. The work was prosecuted with the aid of the following officers:

President,	DR. WM. H. WAHL.
Vice-Presidents,	MR. H. PEMBERTON, Jr. DR. WM. H. GREENE.
Secretary,	DR. WM. C. DAY.
Treasurer,	DR. H. W. JAYNE.
Conservator,	DR. WM. H. WAHL.

Stated meetings were held as required by the by-laws, on the third Tuesday of each month, excepting July and August.

Membership: The number of members on the treasurer's books at the beginning of the year was seventy-two; since that time twenty new members have been elected, eight have resigned, and two were dropped for non-payment of dues; this making a net gain of ten, or a total membership of eighty-two.

Finances: The report of the treasurer recently submitted to the Section shows that the total receipts from various sources during the year exceeded the expenditures, leaving a cash balance in the treasurer's hands at the close of the year.

The attendance upon the meetings has been satisfactory throughout the year, and fully equal to that of 1890.

The highest purpose that the section can serve is, of course, in its capacity as a medium for encouraging and stimulating original research among chemists. That this purpose has been promoted during the past year is well demonstrated by the fact that twenty-nine papers, giving the results of

original investigation, were read before the section and published in the *Journal* of the Institute. In addition to these, four other communications were presented, thus making a total of thirty-three subjects of scientific interest which were considered at ten regular meetings.

Very respectfully submitted,

WM. C. DAY, *Secretary.*

REPORT OF THE ELECTRICAL SECTION.

(For 1891.)

The President and Members of the Franklin Institute:

The Secretary of the Electrical Section begs leave to present the following report of the proceedings of the section, for 1891:

An application for the formation of an Electrical Section, made in accordance with section 3, of article xi, of the by-laws, was presented to the Board of Managers and approved by them, and reported to the Institute with the names of the founders, at its stated meeting, December 17, 1890. After two preliminary meetings, the section was organized on February 24, 1891, by the adoption of its by-laws and the election of the following officers:

President,	PROF. EDWIN J. HOUSTON.
Vice-Presidents,	MR. CARL HERING. MR. PEDRO G. SALOM.
Secretary,	PROF. L. F. RONDINELLA.
Treasurer,	DR. WM. H. WAHL.
Conservator,	

The membership has increased from sixteen founders to sixty-eight active and associate members now on the roll, and the section has lost two members by resignation and one by death.

Seven stated meetings have been held, in accordance with the section's by-laws, on the first Tuesday of each month excepting July and August, with an average attendance of thirty members and visitors at each meeting.

The communications that have been presented during the year, may be found printed in full in the *Journal* of the Institute, and in the present volume of the Proceedings of the section.

In addition to these, many open questions have been discussed, and several electrical devices have been exhibited and described, so that every meeting has been interesting and profitable.

The growth of the section in every way during the short period of its existence has been very gratifying, and it is hoped and believed that it will continue in the future, so that its work may assist in maintaining the scientific *prestige* of the Institute in the department of electricity.

Respectfully submitted,

L. F. RONDINELLA, *Secretary.*

Philadelphia, January 5, 1892.

Franklin Institute.

[*Proceedings of the annual meeting, held Wednesday, January 20, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 20, 1892.

Mr. JOS. M. WILSON, President, in the chair.

Present, 174 members and thirty-four visitors.

Additions to membership since last report, seven.

The annual reports of the Board of Managers, and of the Standing Committees were presented and accepted. (The reports appear elsewhere in this impression of the *Journal*.)

Mr. Henry G. Bryant gave an account of his expedition successfully undertaken in the autumn of last year, to the Falls of the Grand River, in Labrador. The speaker illustrated the subject by the exhibition of a series of lantern slides, from photographs taken by himself. The speaker was heartily applauded for his extremely interesting presentation of the subject.

Prof. Lewis M. Haupt, by invitation, described the project of a ship canal across New Jersey, to unite New York and Philadelphia, and set forth the advantages—commercial and military—to be anticipated from the construction of such a navigable water-way. At the close of Prof. Haupt's remarks, Mr. Heyl offered the following preamble and resolution, which were adopted, viz:

Recognizing the national importance of the proposed ship canal connecting the waters of the Delaware River and Raritan Bay, in the interest of manufacturing and mercantile industries,

The Franklin Institute of the State of Pennsylvania hereby *resolves*, that a committee of three of its members be appointed to coöperate with similar committees of the New York Board of Trade and Transportation, and of the Trades League and other organizations of Philadelphia, in their endeavors to carry the following resolution, recently adopted by them, into effect:

Resolved, That the Members of Congress from this State be requested to urge the introduction of an item in the river and harbor bill, making an appropriation of a sum not less than $25,000 for an examination, survey, and report upon a twenty-four foot navigable channel between Raritan Bay and the Delaware River; said appropriation to be expended by a commission to be composed of one citizen from each of the States of New York, Pennsylvania and New Jersey, to be appointed by the Governors thereof, and one officer of the United States Corps of Engineers, one officer from the Navy, and one officer from the United States Coast Survey.

Mr. John Carbutt exhibited a suite of beautifully colored lantern views, by Japanese artists, relating to the recent destructive earthquake that had devastated a portion of Japan. (The pictures were obtained from the col-